Higgs Boson Physics at CDF

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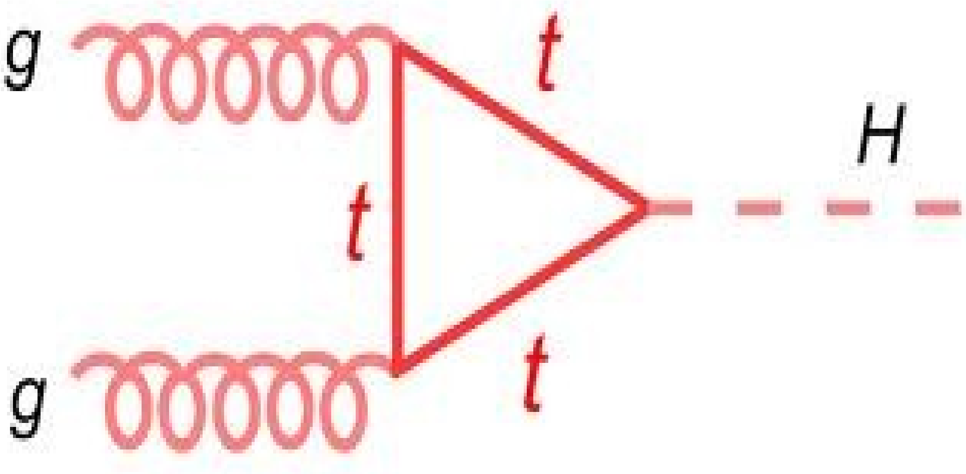
SLAC
Experimental Seminar
25 September 2012

A Higgs-Like Boson Discovered!

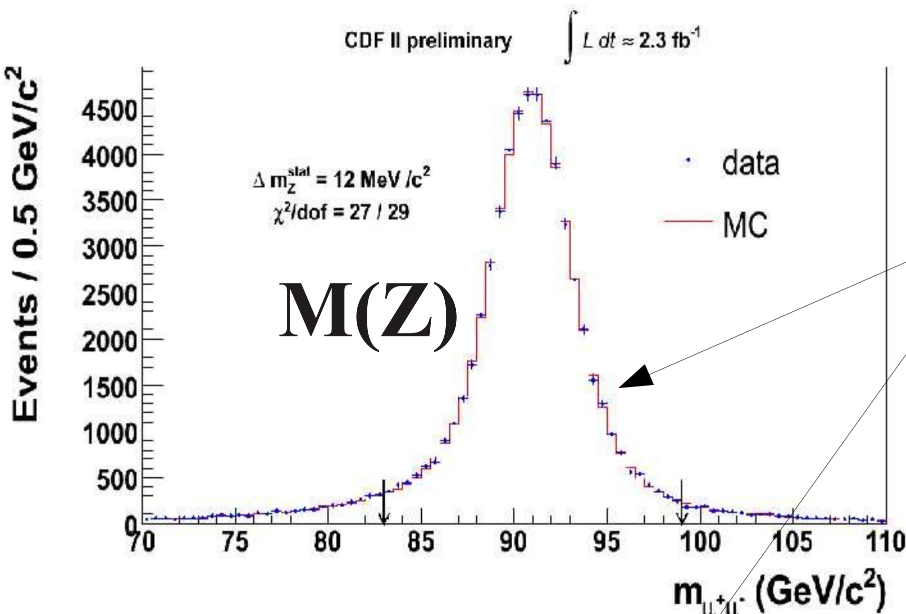
- July 4th, simultaneous, independent announcement of discovery by ATLAS and CMS
  - Observed ~5 σ significance
  - Produced in gluon and vector boson fusion
  - Decays to pairs of:
    - Photons, W bosons, Z bosons
- Definitely know:
  - Is a boson, not spin 1.
  - Couples (directly) to W and Z
- Reasonable questions:
  - Couplings to fermions? Seems reasonable, but need to see directly
  - Spin and parity?
  - Other new particles within reach?

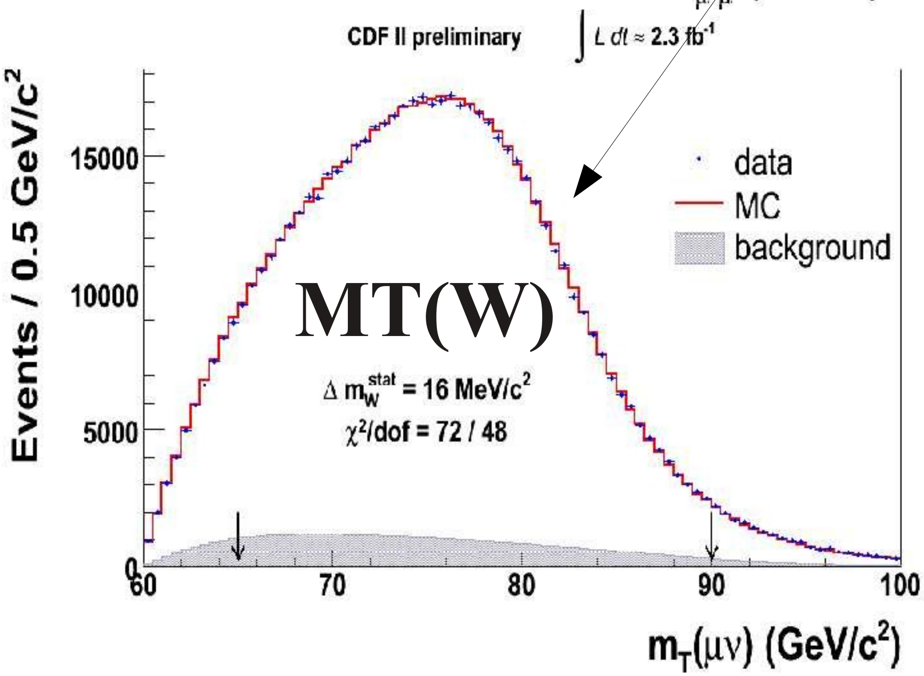


Overview

- Why we thought it was there
- How we looked
- What we saw
- What we might see soon

Motivation

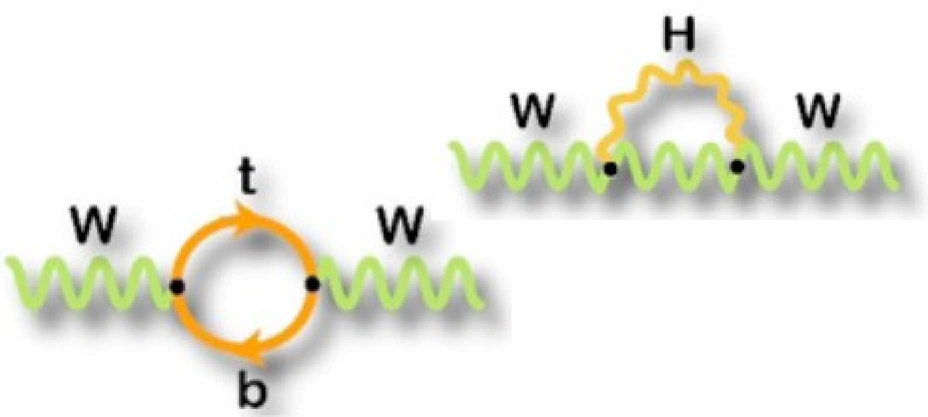


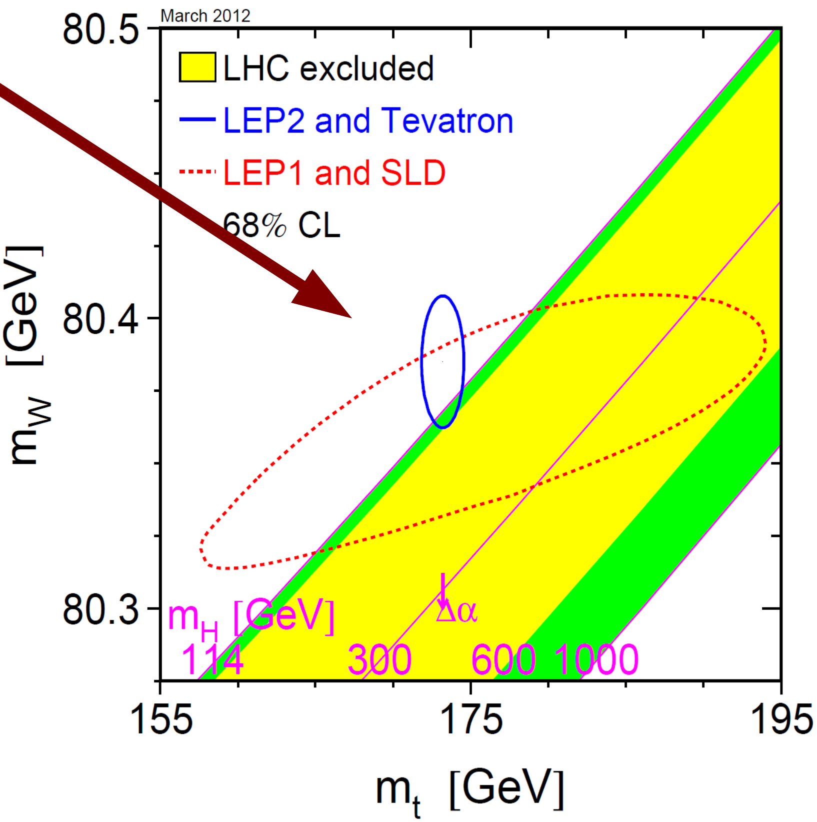


- **Gauge invariance suggests massless W and Z bosons**
  - **W, Z observed to be massive**
- **In SM, W&Z observable masses arise via electroweak symmetry breaking**
- **Ground breaking work on EWSB:**
  - **F. Englert, R. Brout,**
    - **PRL 13 (9): 321–323.**
  - **P.W. Higgs,**
    - **PRL 13 (16): 508–509.**
  - **G.S. Guralnik, C.R. Hagen, T.W.B. Kibble,**
    - **PRL 13 (20): 585–587.**
- **Proposed mechanism of EWSB predicts an additional observable scalar particle.**
  - **Observable at the Tevatron?**

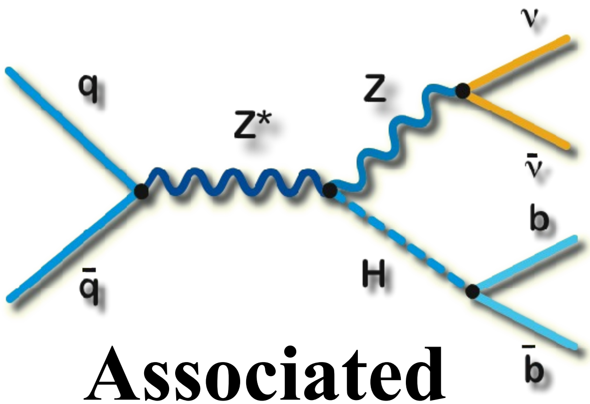
Experimental Status (June)

- **Resulting boson mass is unpredicted by theory**
  - **Mass determines production and decay rates (next slide)**
- **Indirect constraints (MW, Mtop) prefer a SM Higgs Boson with MH below 158 GeV**
  - **CDF&DØ 2012 W mass!**
- **Pre-Discovery Direct Searches: 95% CL Exclusions of MH in SM:**
  - **LEP: Exclude MH < 114 GeV**
    - **arXiv:0602042v1**
  - **Tevatron: Exclude MH in [156,177] GeV**
    - **arXiv:1107.5518**
  - **LHC: Exclude MH <115, or [~127, 600] GeV**
    - **arXiv:1202.1408 (ATLAS)**
    - **arXiv:1202.1488 (CMS)**

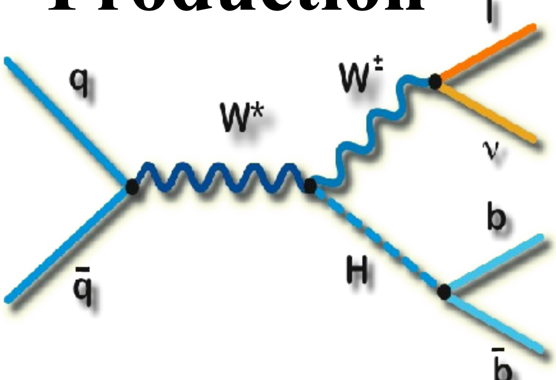




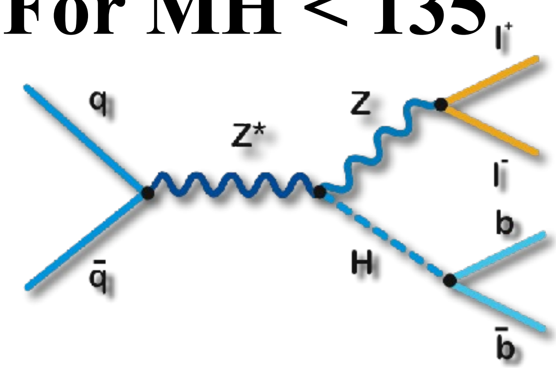
SM Higgs Boson Production in $p\bar{p}$ Collisions

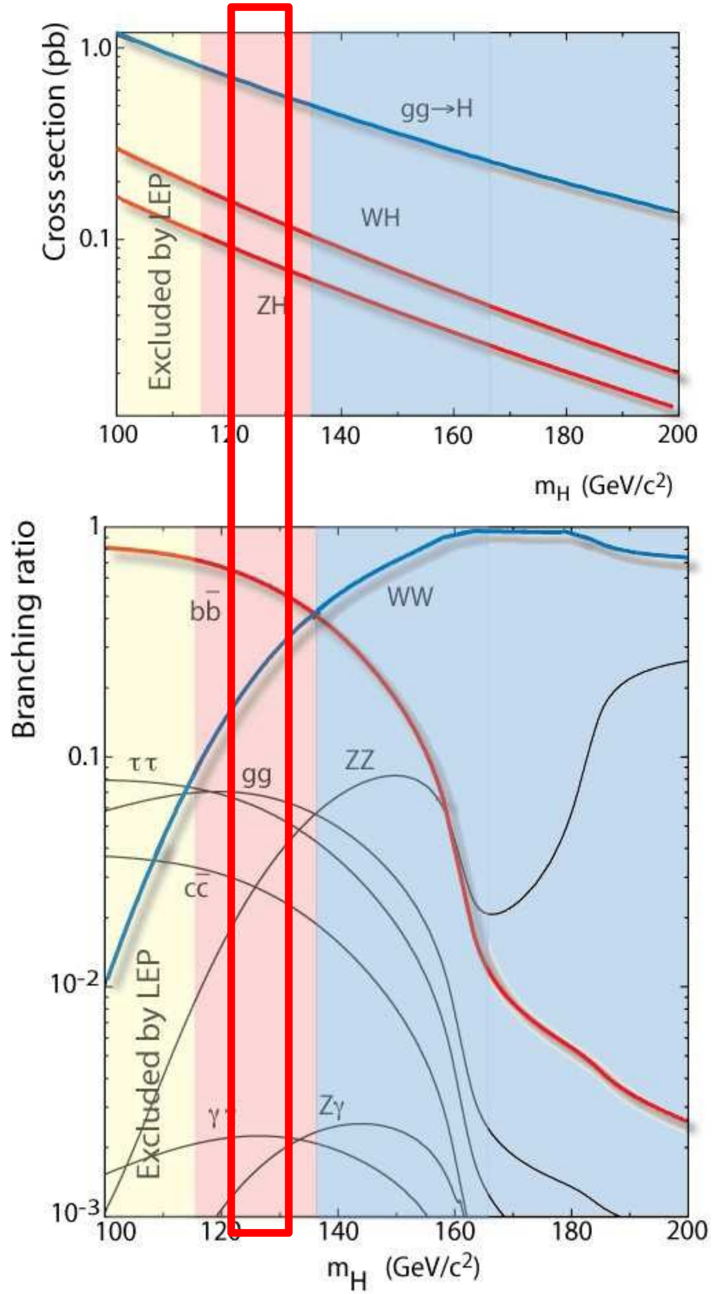


Associated Production

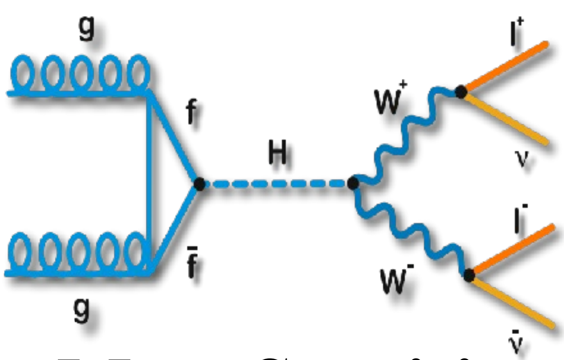


Most Sensitive For MH < 135





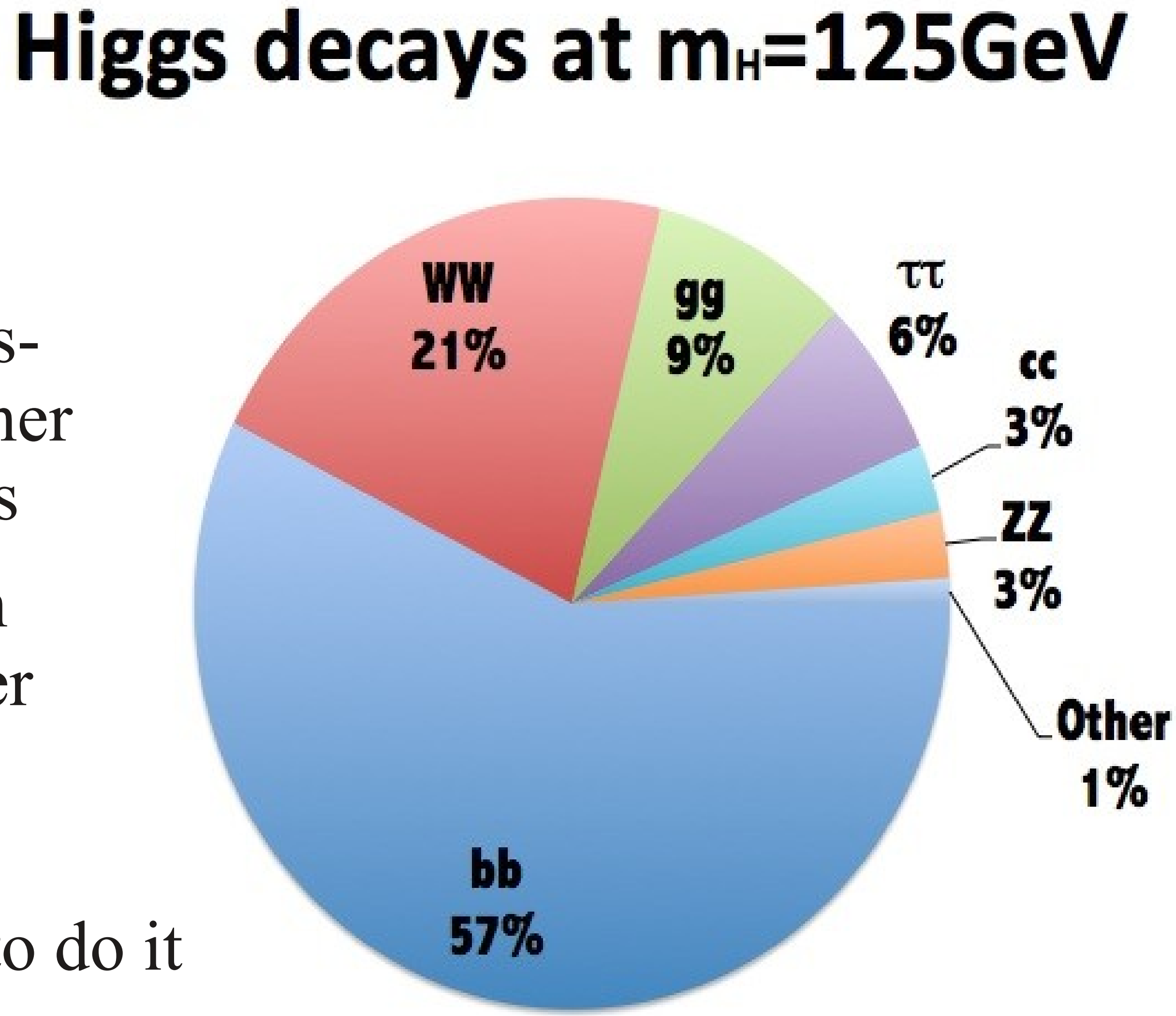
Direct Production



Most Sensitive for MH > 135

Decay Modes of the SM Higgs Boson

- Mostly bottom quarks!
  - QCD bb >8 orders-of-magnitude higher at hadron colliders
  - Photon and lepton backgrounds better controlled
  - bb is a dirty job, but someone has to do it
  - Need most of these decays to be confident its really a SM Higgs boson!



The Tevatron compared to SLC

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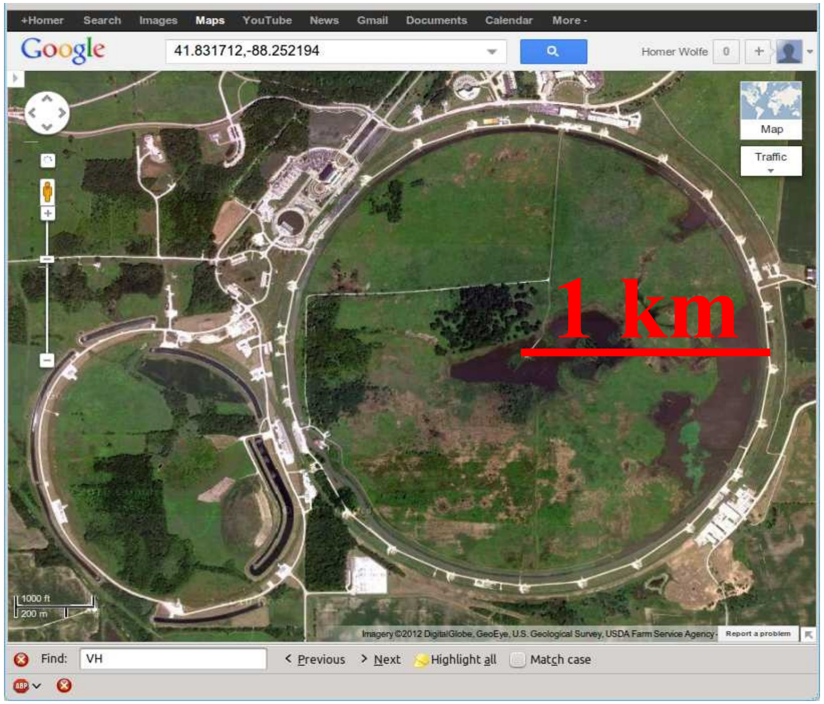
SLAC

The Tevatron, Batavia IL, USA

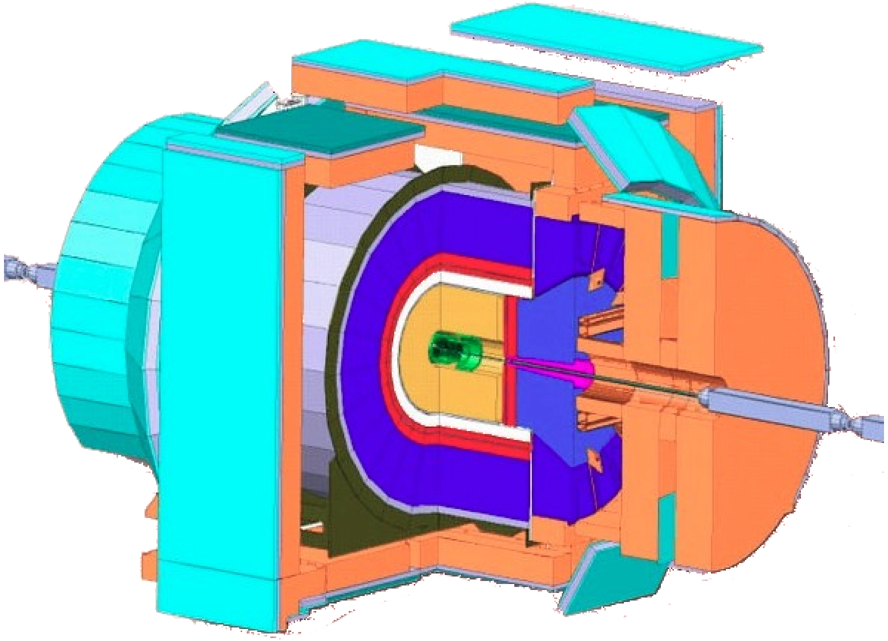


- Superconducting storage ring
  - 1 km radius, 1 beam-pipe
  - Collisions 1985-2011
- Run II: Mar 2001-Sept 2011
- Produced $p\bar{p}$ collisions at 1.96 TeV
  - 36x36 bunches
  - ~E10-E11 particles per bunch
  - ~21μs per revolution
  - ~1.5 MJ beam energy
    - Compare to ~200 kJ for HER
    - Compare to ~400 MJ for LHC
- Not like a lepton collider:
  - Quark, gluon scattering
  - PDFs means << 2 TeV goes into hard scatter

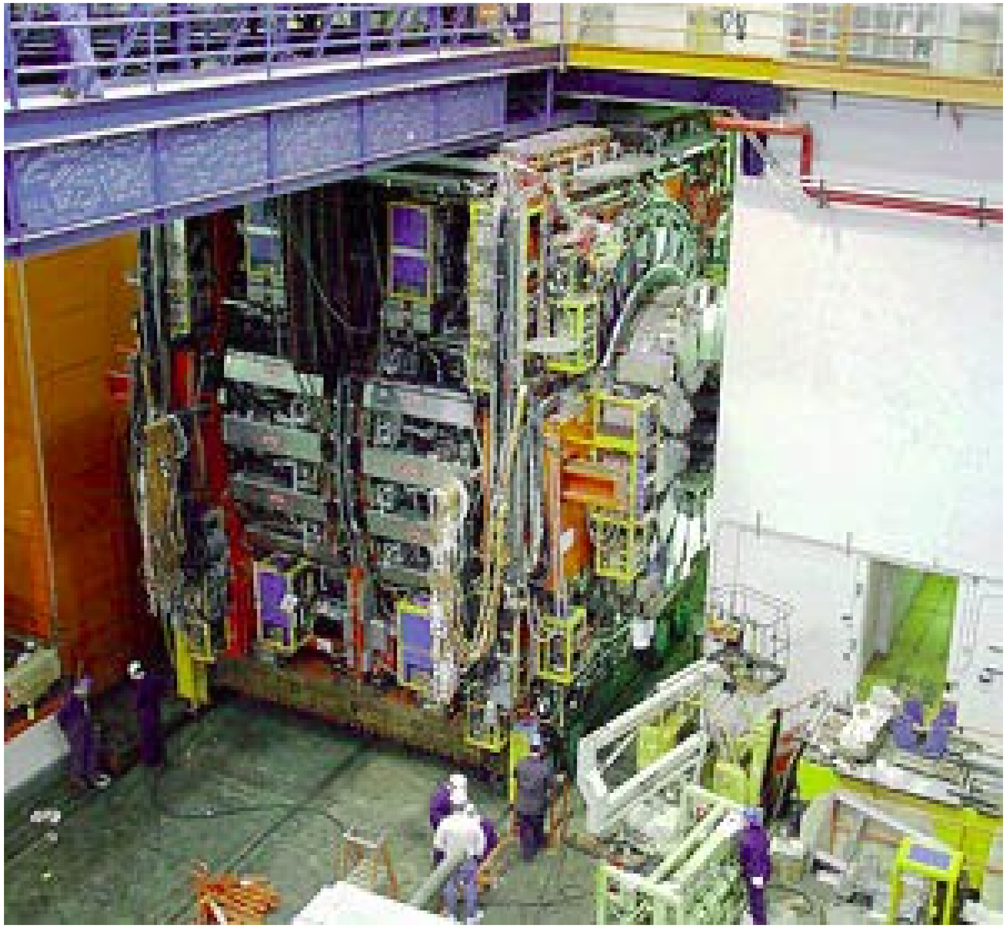
Detectors at The Tevatron

- The Tevatron's collisions were recorded by two general purpose experiments: CDF and DØ

The Collider Detector at Fermilab

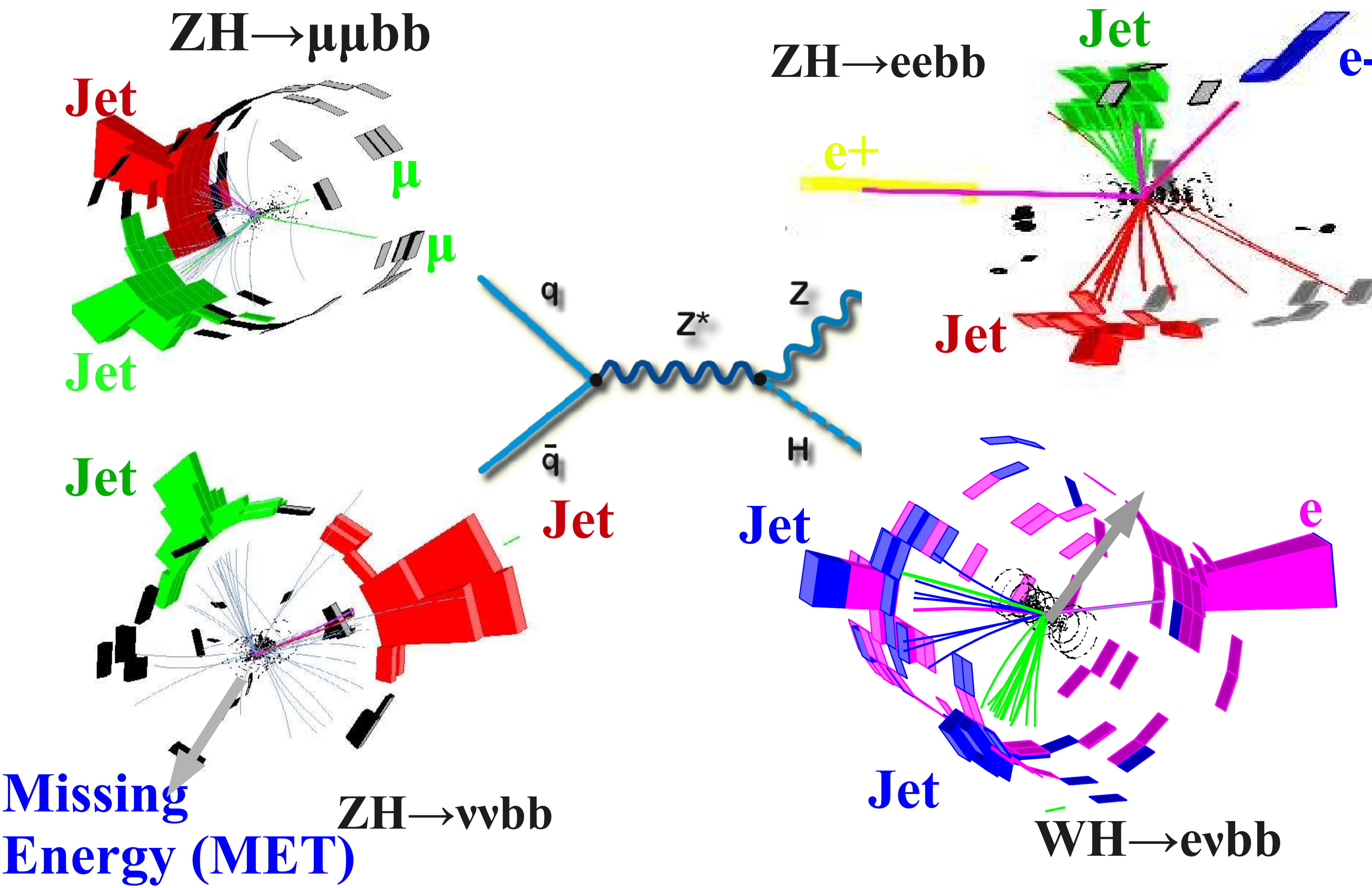


- **Silicon tracking $|\eta|<2\text{-}2.5$**
- **Drift cell tracker**
  1.4 Tesla field, $|\eta|<1.1$
- **Calorimeter:**
  Pb/Fe+Plastic Scintillator
  $|\eta|<3.2$
- **Muon chambers: $|\eta|<1.5$**
- **Jet Energy Scale Uncertainty (High-ET): 2-3%**



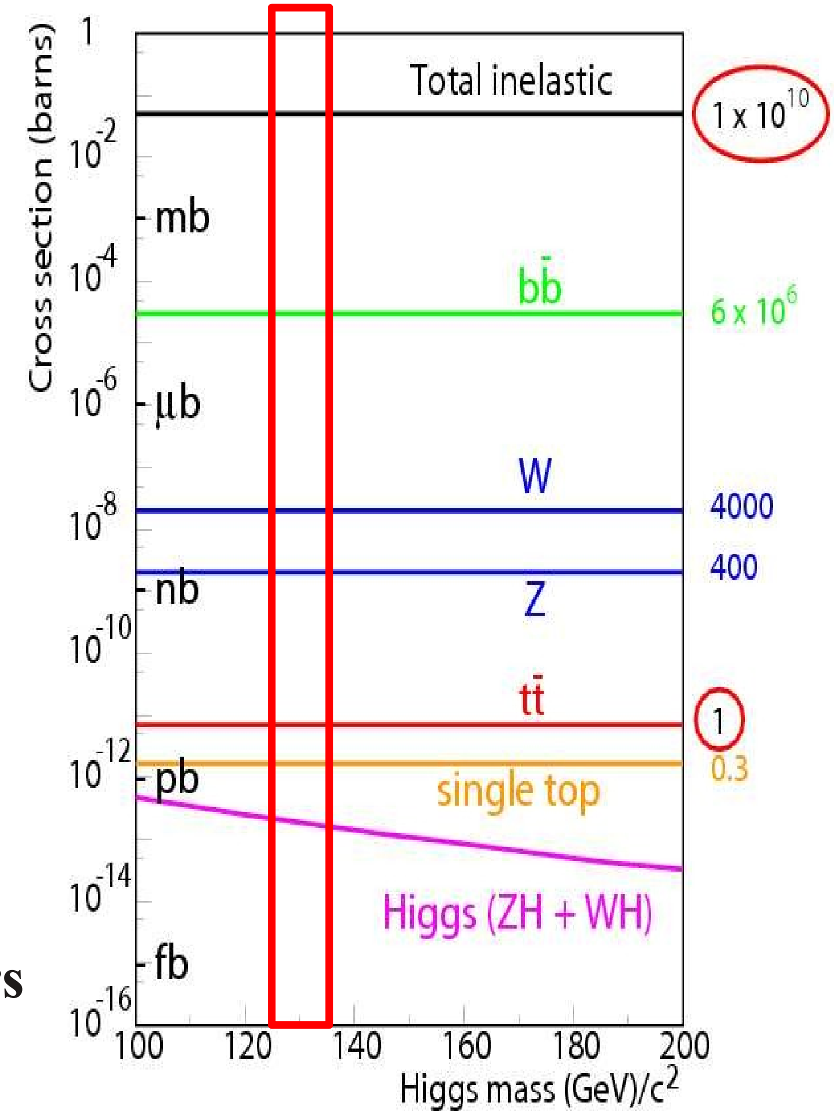
~4500 Tons (Central)
~400 Tons (Muon Walls)
~800 Tons (End Toroids)

Candidate Associated Production Events in Data at CDF



Data Taking Conditions

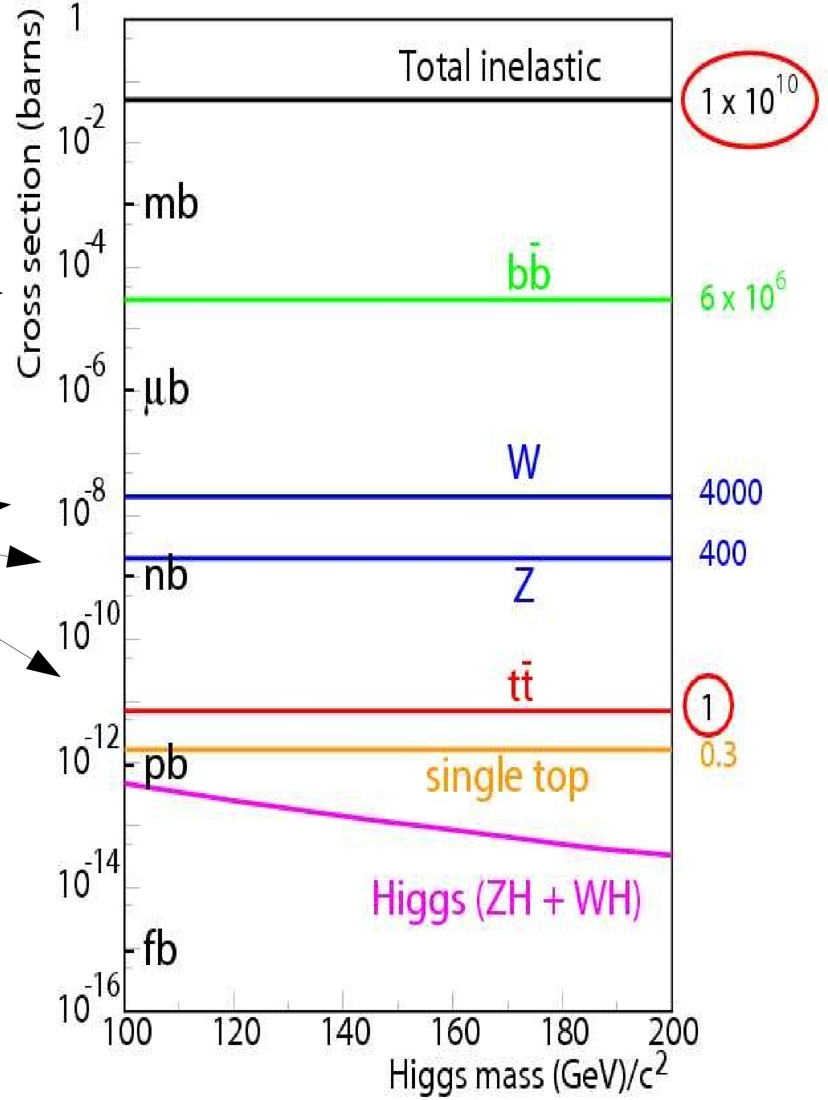
- **The Tevatron bunch crossing rate was ~2.5 MHz**
- **Full readout saturated at ~100 Hz**
- **Rates at L=1e32 cm^{-2}s^{-1}:**
  - **Jets (ET>40 GeV): ~300 Hz**
  - **W: ~3 Hz**
  - **Top Pair: ~25/hour**
  - **SM Higgs ~10/week:**
- **Triggers designed to select events on the fly, with varying degrees of reconstruction**
  - **keep most signal-like events, discard others**
  - **Mixture of custom hardware and commodity PCs**



Data Taking Conditions

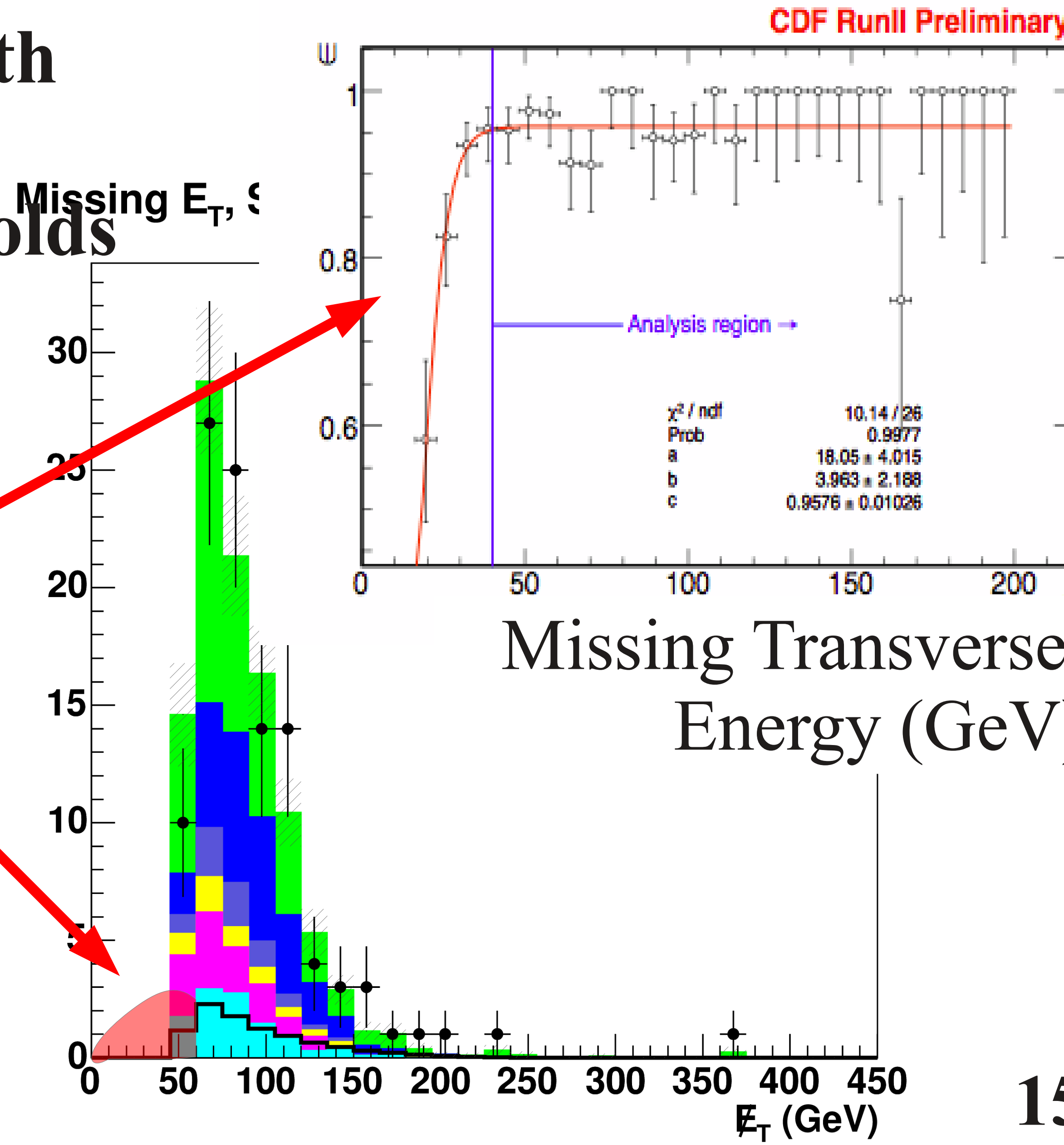
Avoid this Background

Prefer These



Trigger Efficiencies

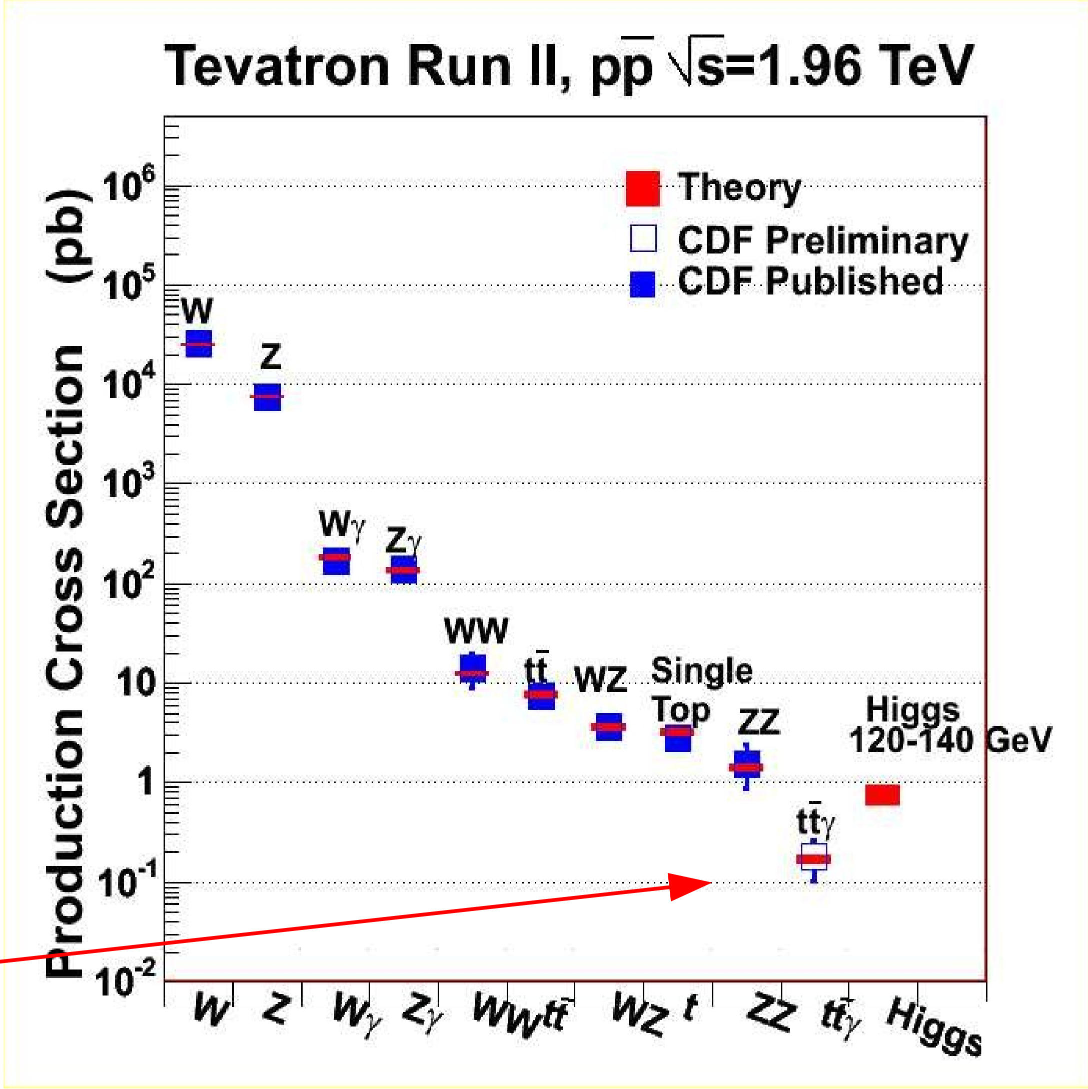
- **Data taking bandwith budgets dictate MET trigger thresholds be set near or above kinematic peak.**
  - Lost signal!
- **I'll tell you later how we got some of it back!**



Missing Transverse Energy (GeV)

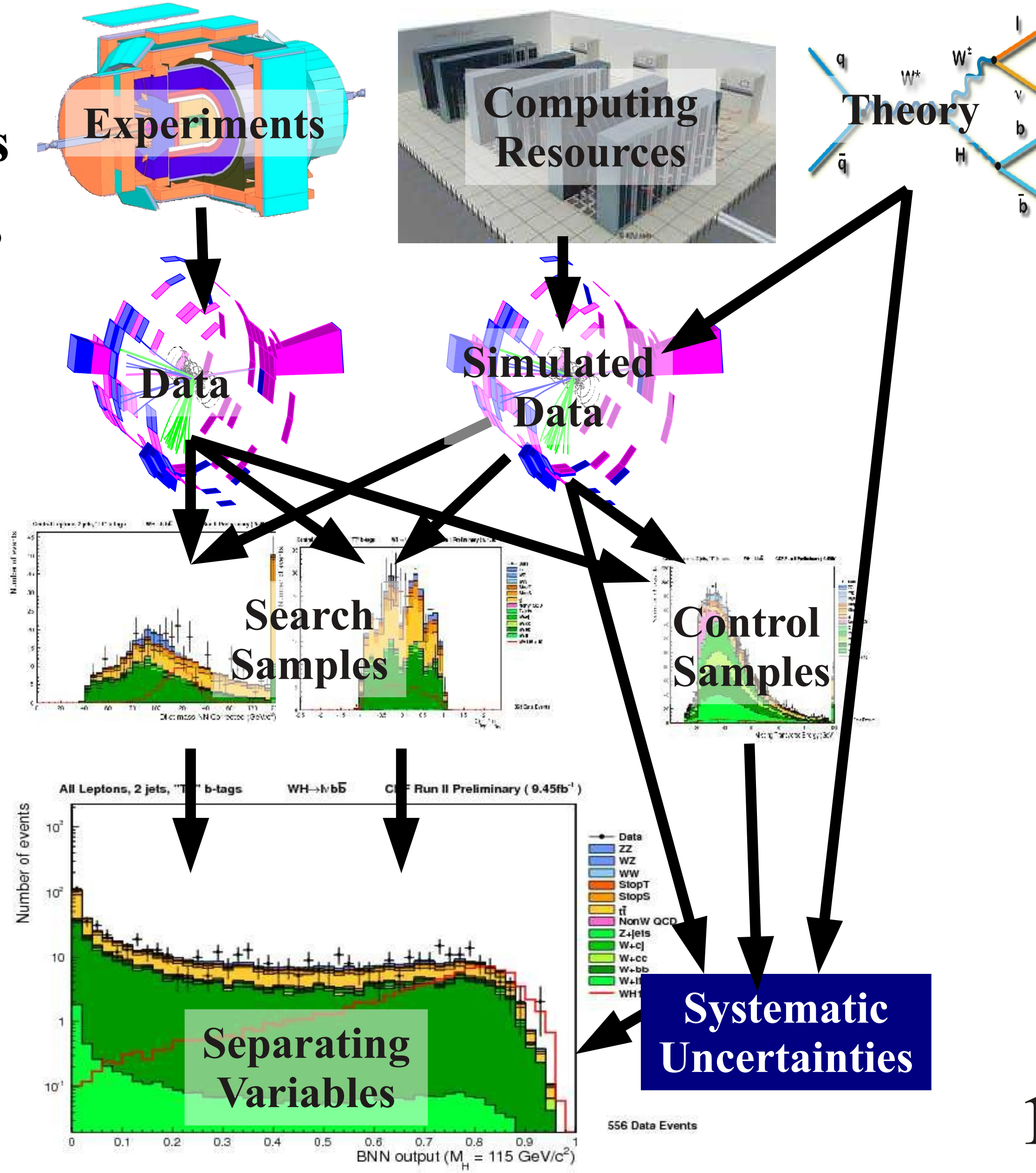
The Tevatron RunII Datasets

- Full results presented here
- 11/fb on tape
  - ~10/fb good for analysis
- Typical #vertices/event 1-3
- Candidates in 10/fb:
  - B0s→J/ψφ : ~10K-20K
  - $t\bar{t}$→e/μ+>=1 b-jet : ~2000
  - Z→ee/μμ : ~600K
  - (W→e/μ)+dijet : ~100K
  - >30 GeV photons : ~20M
  - ZZ→4l: ~10
  - $t\bar{t}$+γ→γ+l+jets: ~50



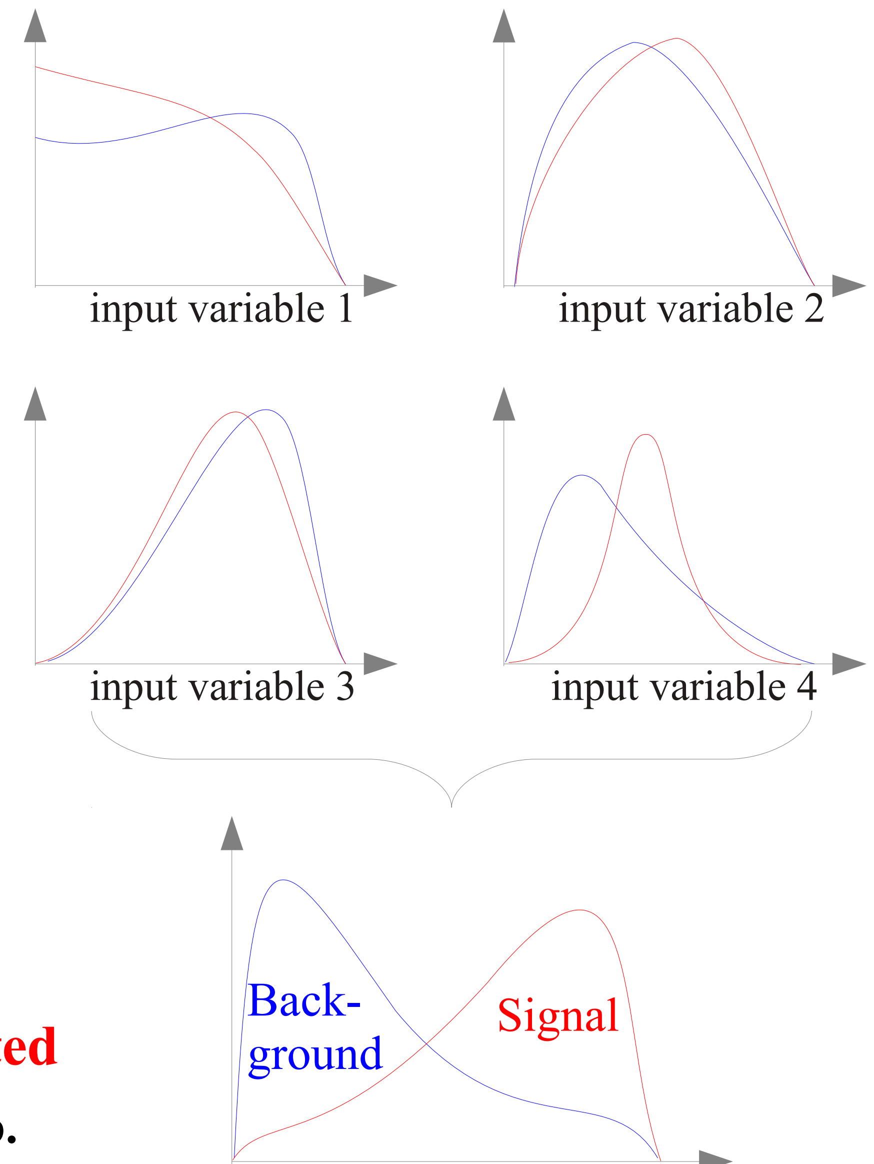
From Events to Statements About Signal

- Collect data events
  - Reconstruct their properties
  - Select signal-like candidates
  - Select control samples
- Simulate the background and signal components
  - Estimate uncertainties
- Sift events according to signal significance
  - Multivariate discriminants
- Make a statement about compatibility w/ background or s+b hypotheses

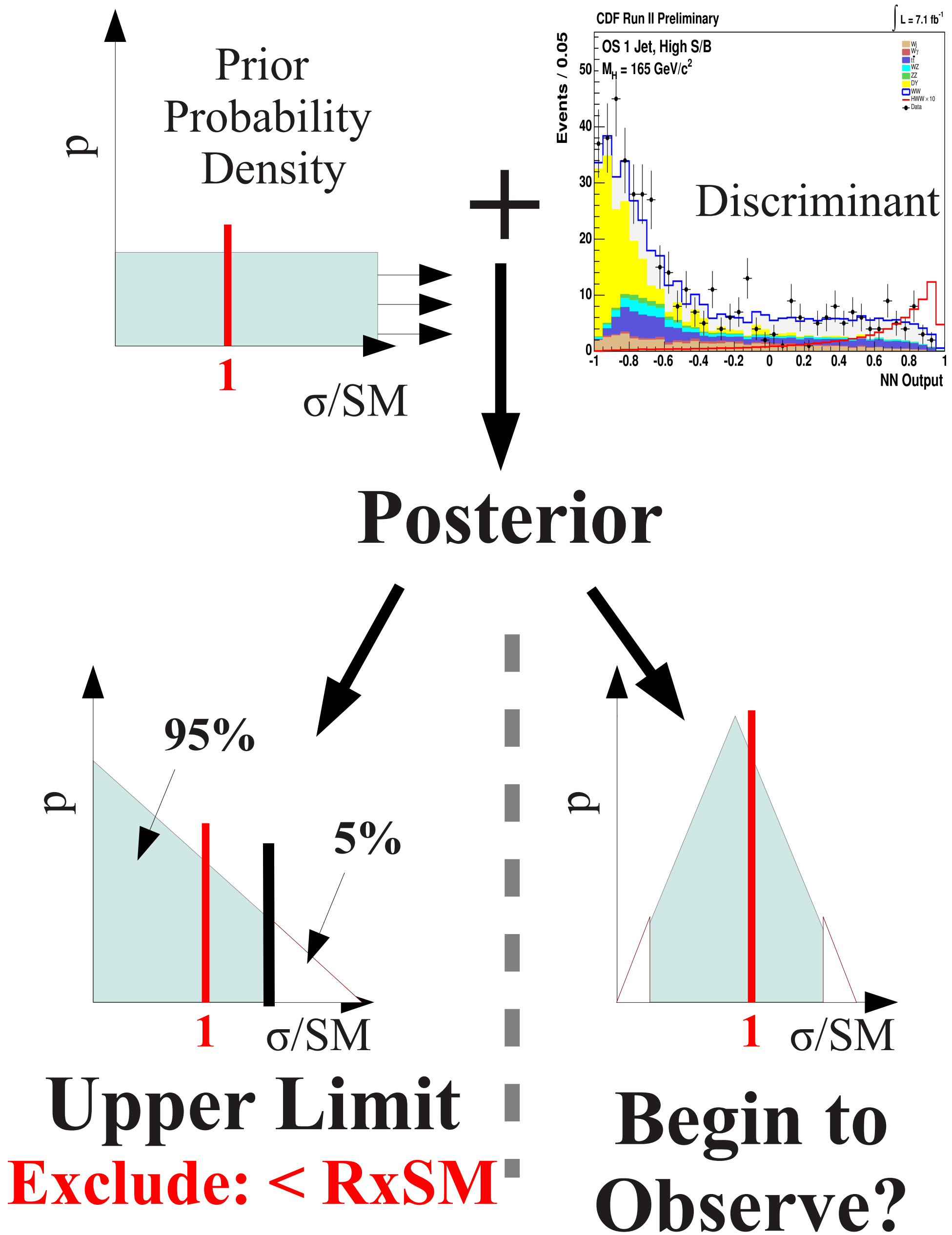


Creating Discriminating Variables

- Identify regions of high signal density
- Some analyses, like $\gamma\gamma$, use the "reconstructed Higgs mass".
- In WH, using M(jj) is about 75% as strong a **multivariate method**
- Many Options:
  - Scattering m**atrix element** (ME) or dynamic likelihood methods (DLM)
  - CDF often uses **kernel machines** like Neural/Bayesian/ensemble networks, SVMs
  - DØ often uses boosted d**ecision trees** (BDT)
  - **Negligible performance difference between MVA methods when thoroughly implemented**
    - **See CDF WH search with NN and ME in 5.7/fb.**
    - Human effort in implementation and intuition tends to govern preferences



Bayesian Searches (CDF)



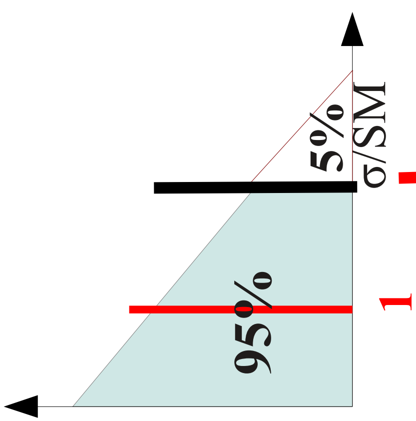
- Make a statement about belief in Cross section ratio: R=σ/σ(SM)
- Compute joint-poisson likelihood
  - Compatibility of data with each hypothesis
- Flat prior: R=[0,MAX]
- Nuisance parameters:
  - Detector response, background
  - cross sections, PDFs, etc.
- Integrate likelihood over nuisance parameters:
  - Produces **posterior probability density as function of R alone**

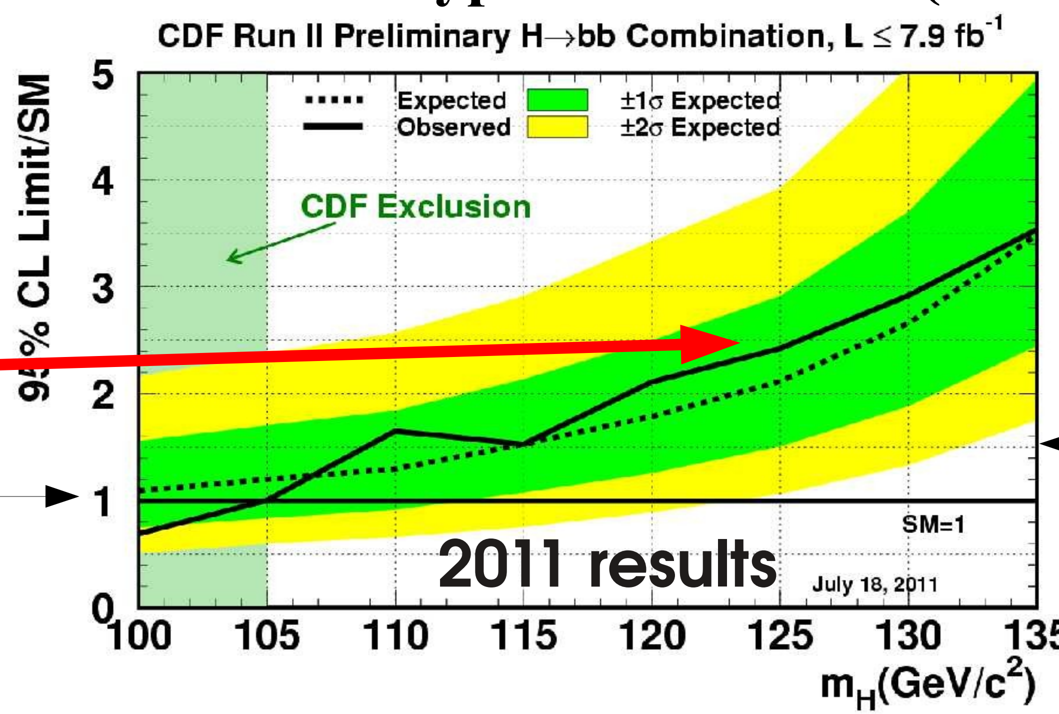
Bayesian vs. Frequentist

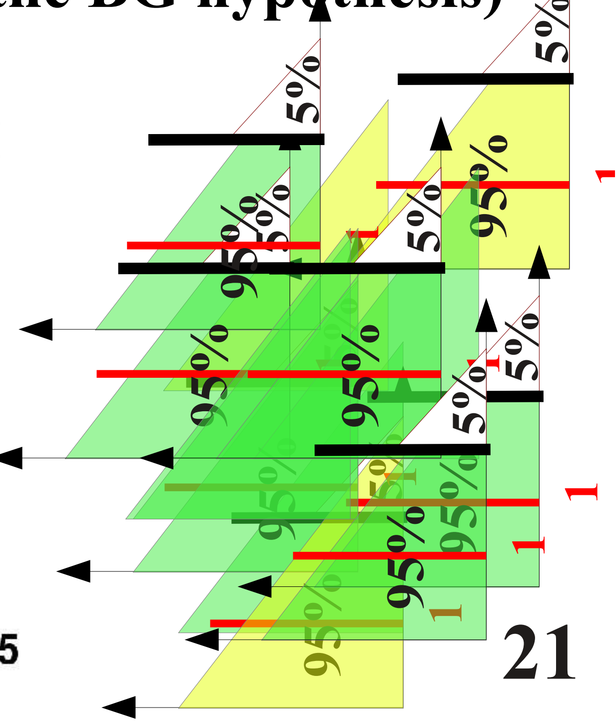
- D0, ATLAS, CMS all use
  Modified Frequentist limit calculations
  - Bayesian and M.F. Agree numerically to ~1%
    for searches with large numbers of observed events.
- Technical advantage
  - Bayesian method relies on **integrating** over nuisance parameters
    - Profile likelihood method relies on a fitting procedure,
      which involves computing **derivatives**
  - Integrating is less sensitive to
    discontinuities in nuisance parameter priors

Bayesian Searches (CDF)

- **Perform this analysis for each assumed Higgs Mass:**
  - **Data (Observed upper limit)**
  - **Simulation: (Expected sensitivity)**
    - **Construct ensemble of *background-only* pseudoexperiments**
      - **Each pseudoexperiment has same statistical uncertainty as data, selected from one systematic assumption**
    - **Shaded bands show typical excursions (for the BG hypothesis)**

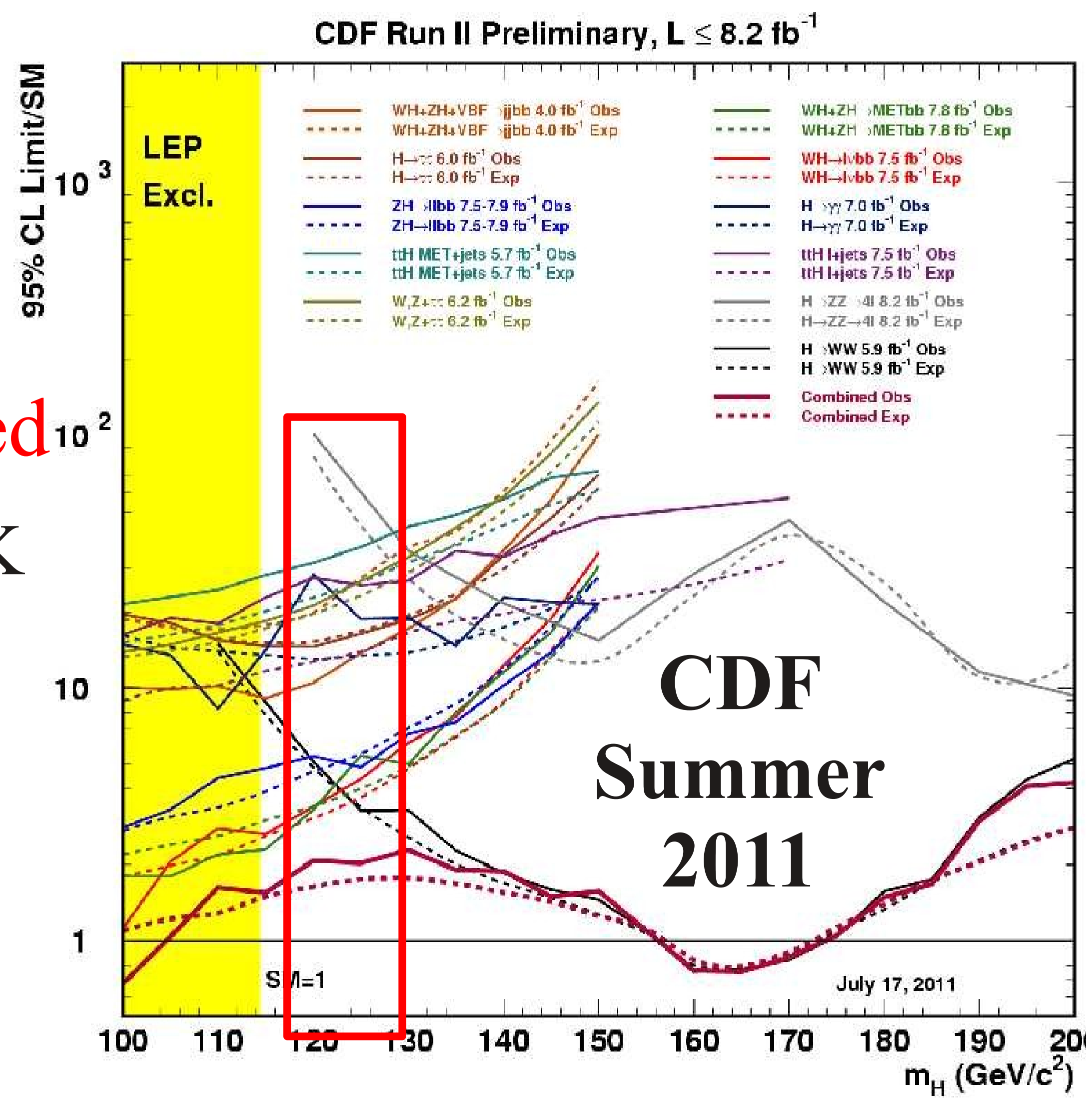






Overview of Individual Higgs Searches

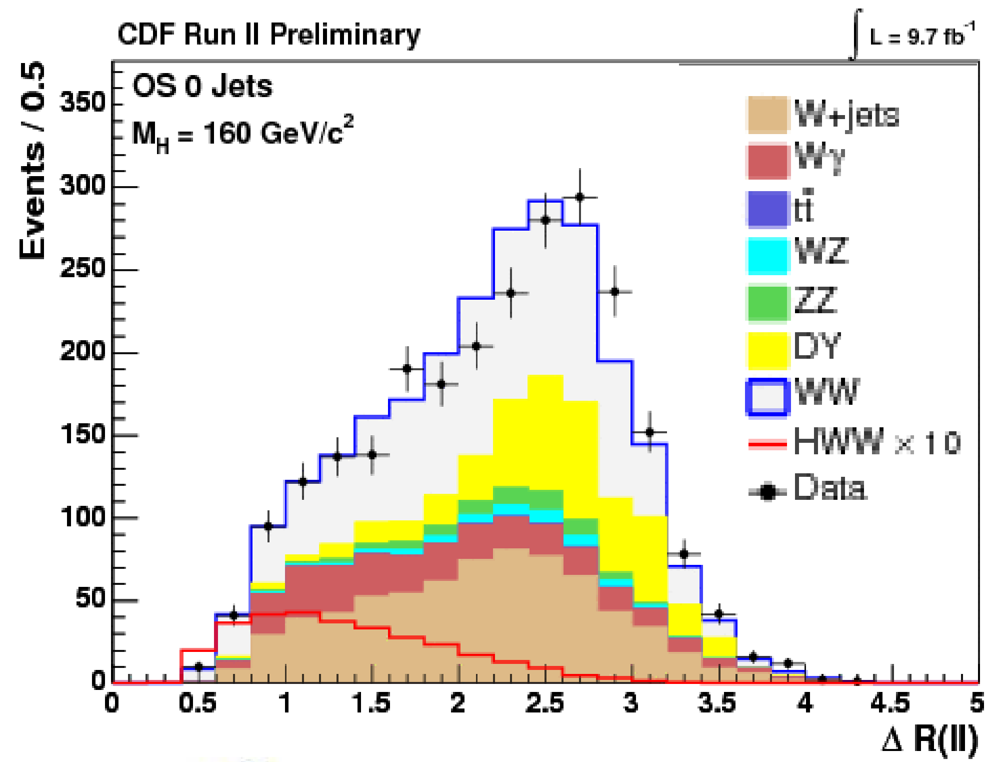
- **For July 2012 results:** SM predicts ~167 Higgs events (125 GeV) reconstructed and selected
  - SM background of ~200K
- 11 CDF analyses:
  - **~88 orthogonal sub-channels.**
- In region 115-127 GeV, WH,ZH,VH, and WW contribute ~90% of total weight of combination.

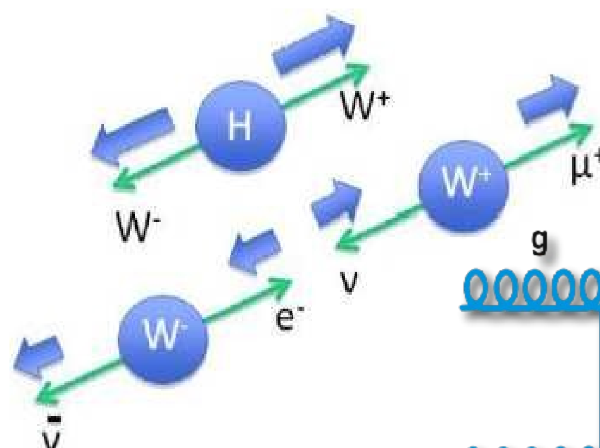


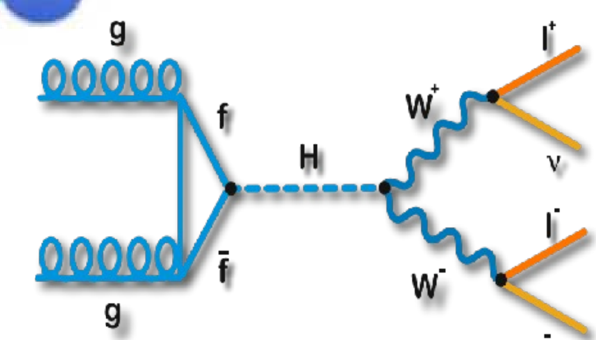
H → WW → lνlν

Identify 2 leptons, separate by jet multiplicity

- Capitalize on scalar nature of Higgs:
  - Spin correlations
  - Leptons closer in signal than background
- **2012 improvement:**
  - Redefine lepton "isolation"
  - Avoid mutual isolation veto for two nearby leptons.
  - More acceptance!



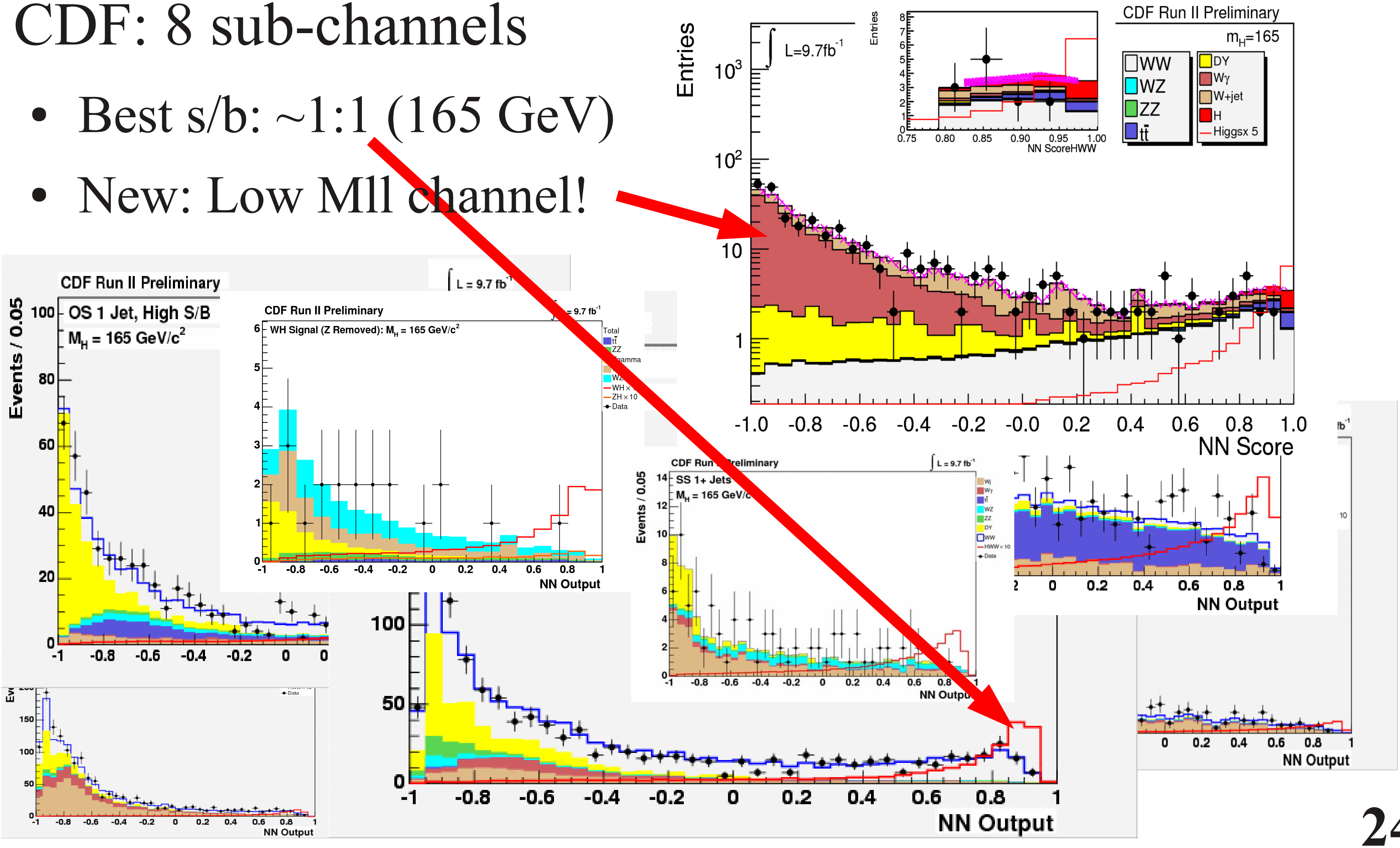




High-Mass Combined Searches

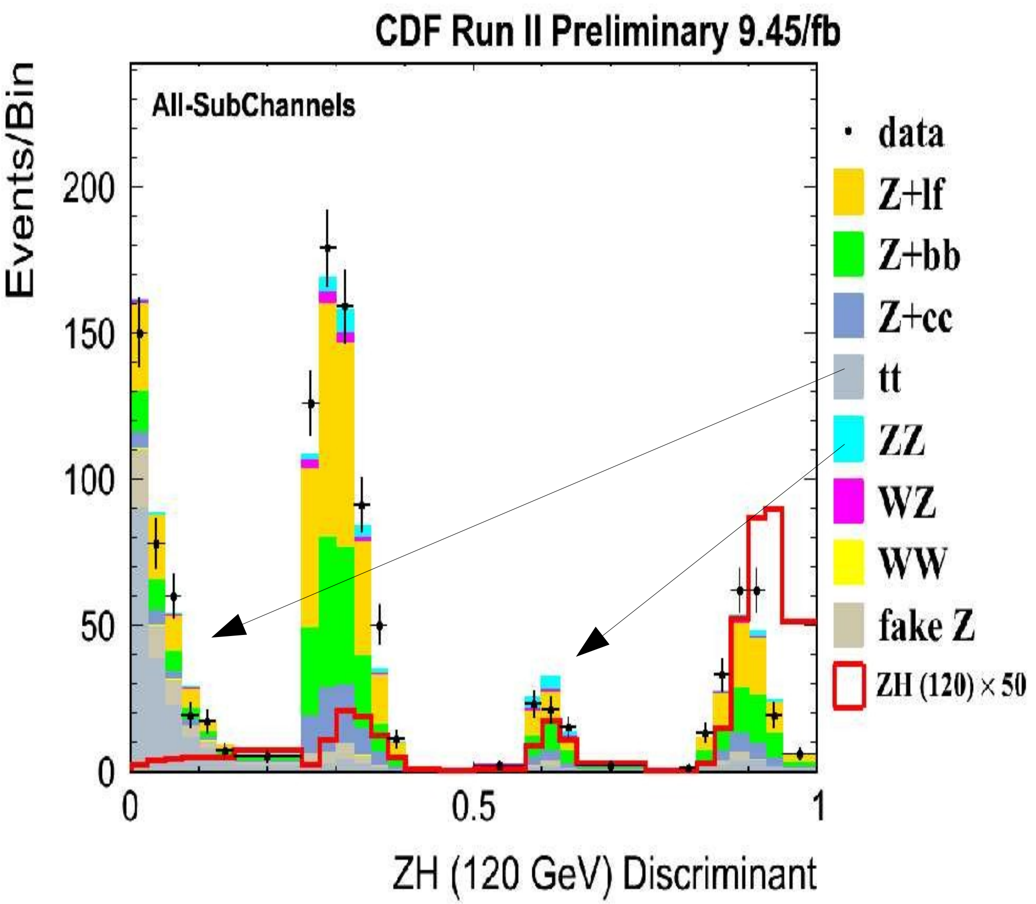
CDF: 8 sub-channels

- Best s/b: ~1:1 (165 GeV)
- New: Low Mll channel!



Why So Many Categories?

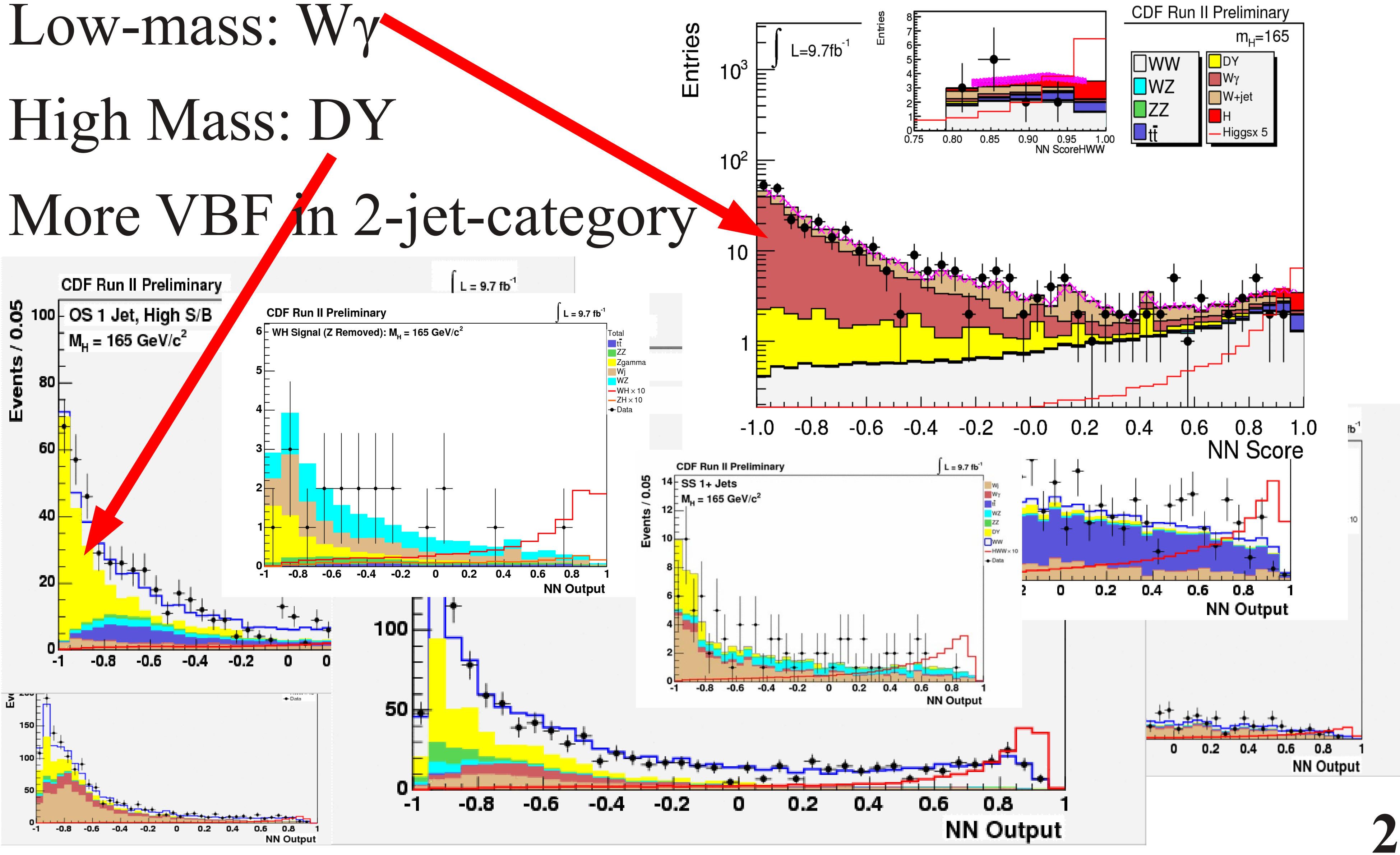
- Three major advantages
  - Sensitivity is roughly proportional to integrated signal/√BG
    - Weaker categories dilute stronger ones
  - Individual categories are affected by nuisance parameters in distinct ways
    - Isolating distinct samples can constrain nuisance parameters in situ!



- **NEW**: different production and decay mode sensitivities in different categories?
  - Fermionic-to-bosonic coupling ratios!
  - See J. Wacker's colloquium talk from Sep 24.

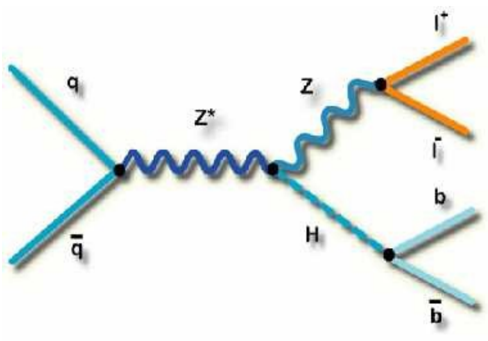
High-Mass Combined Searches

- Low-mass: Wγ
- High Mass: DY
- More VBF in 2-jet-category

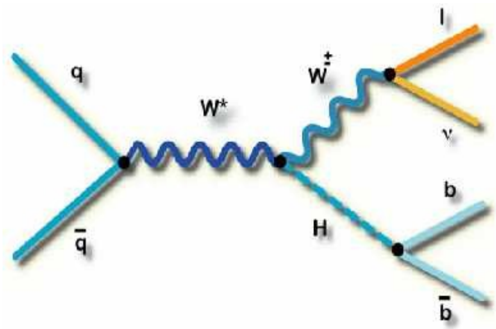


Associated Production Channels

$ZH \to l^+l^-b\bar{b}$



$WH \to l^{\pm}\nu b\bar{b}$



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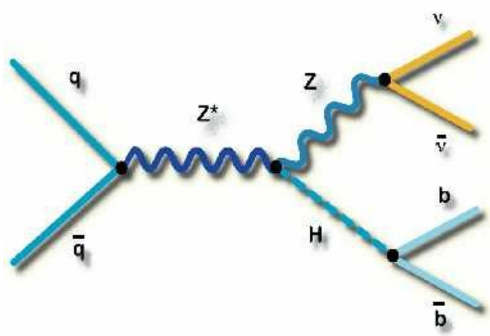

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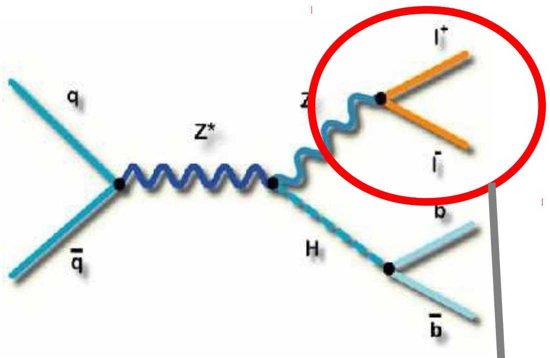
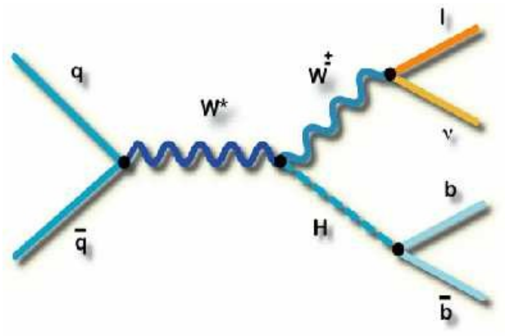
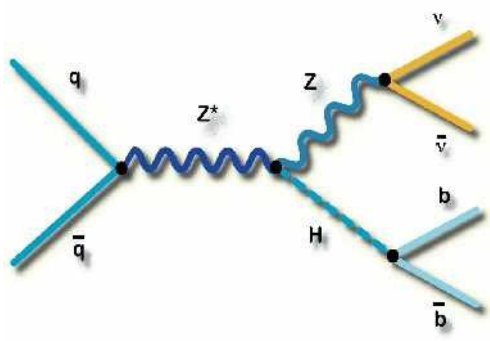
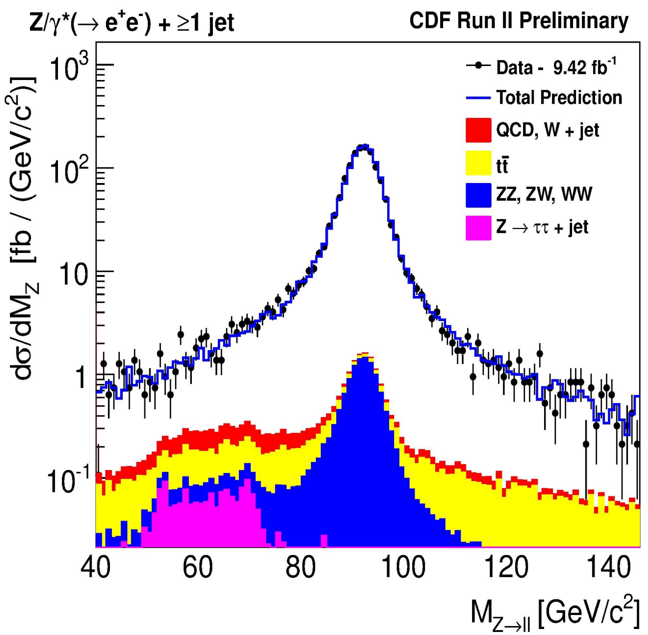






$Z \to e^+e^- +$ jets



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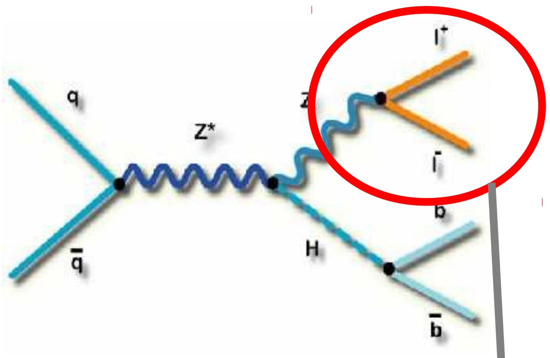

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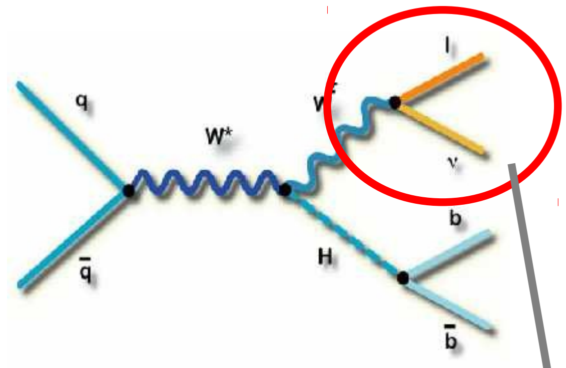

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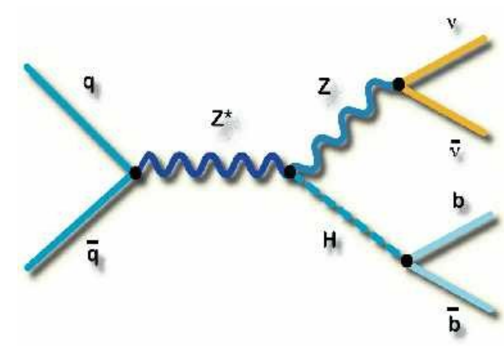

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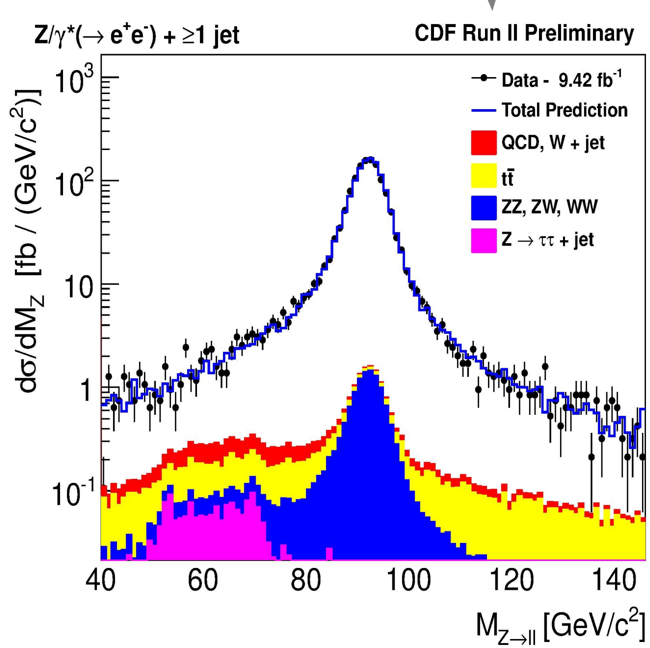

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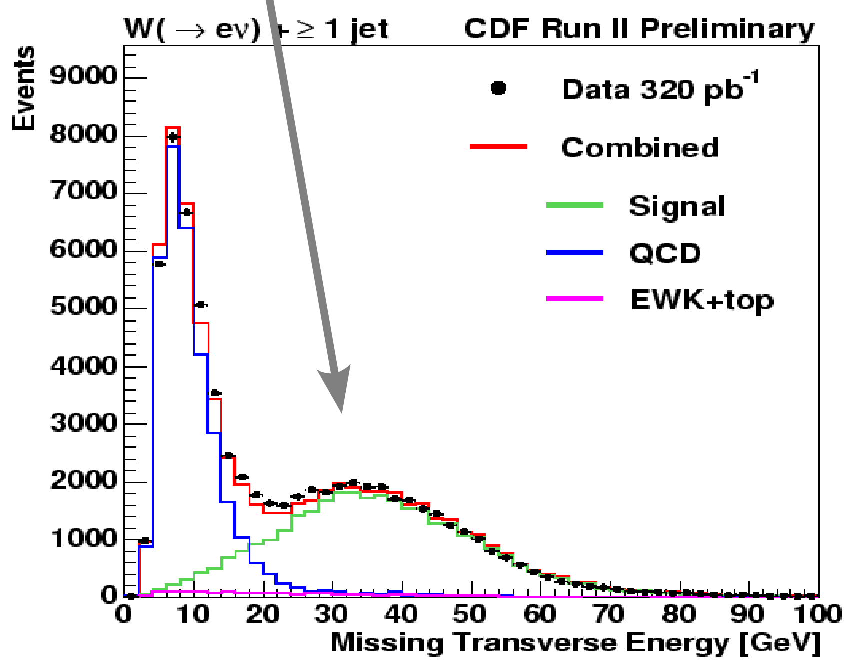

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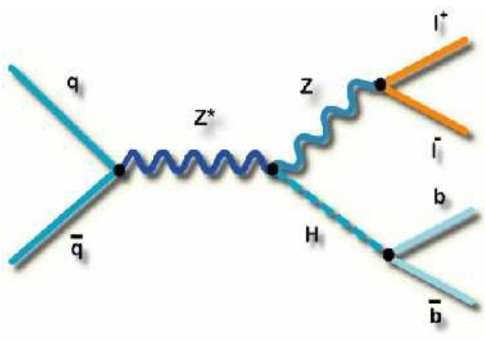

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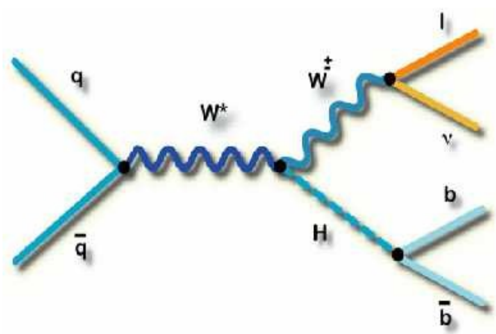

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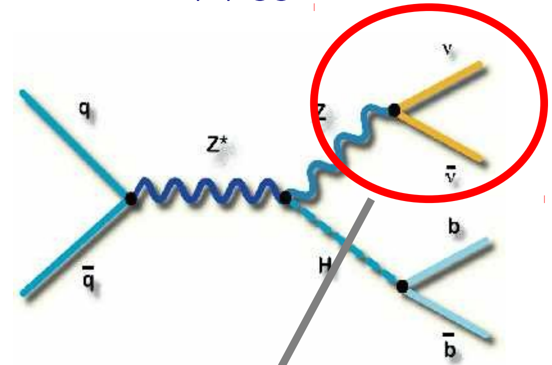
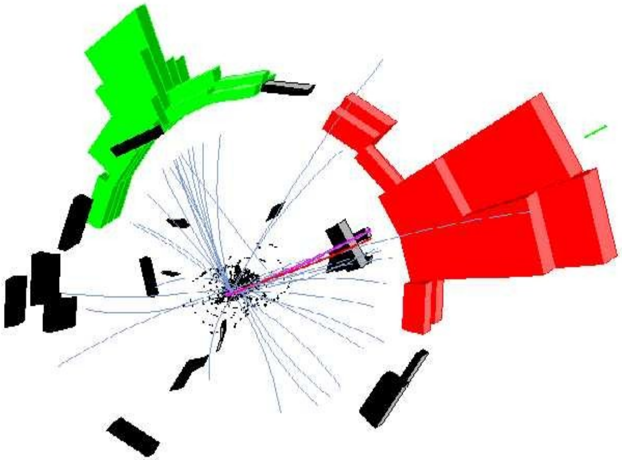
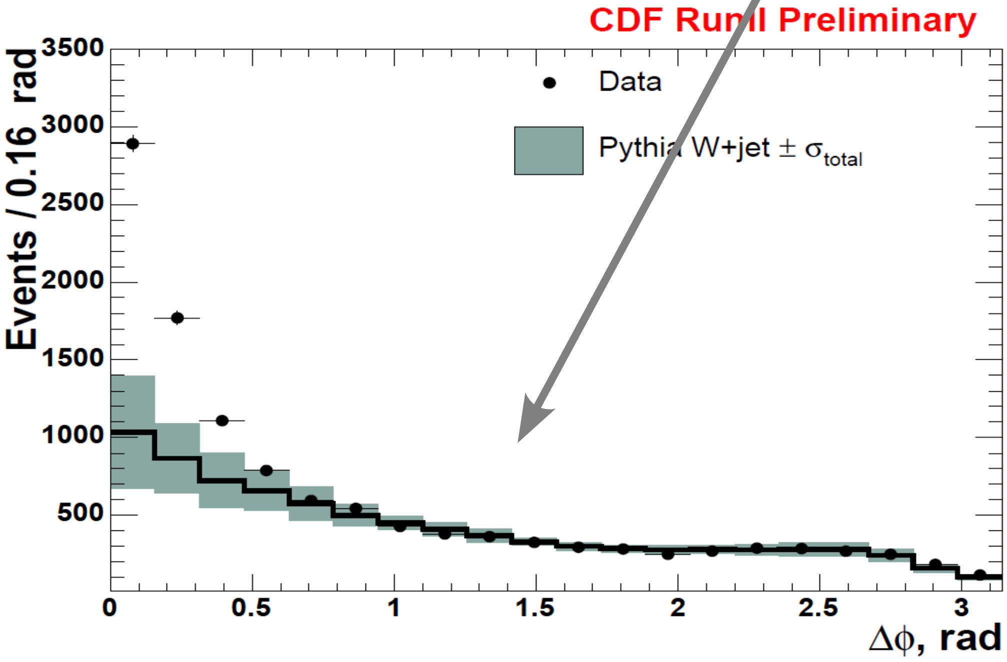
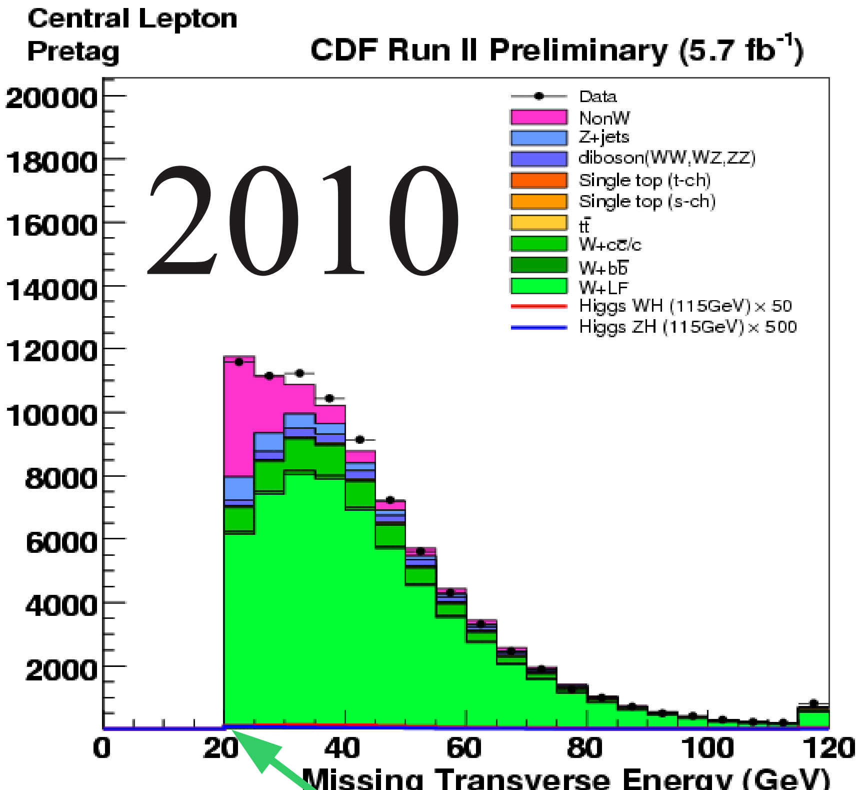
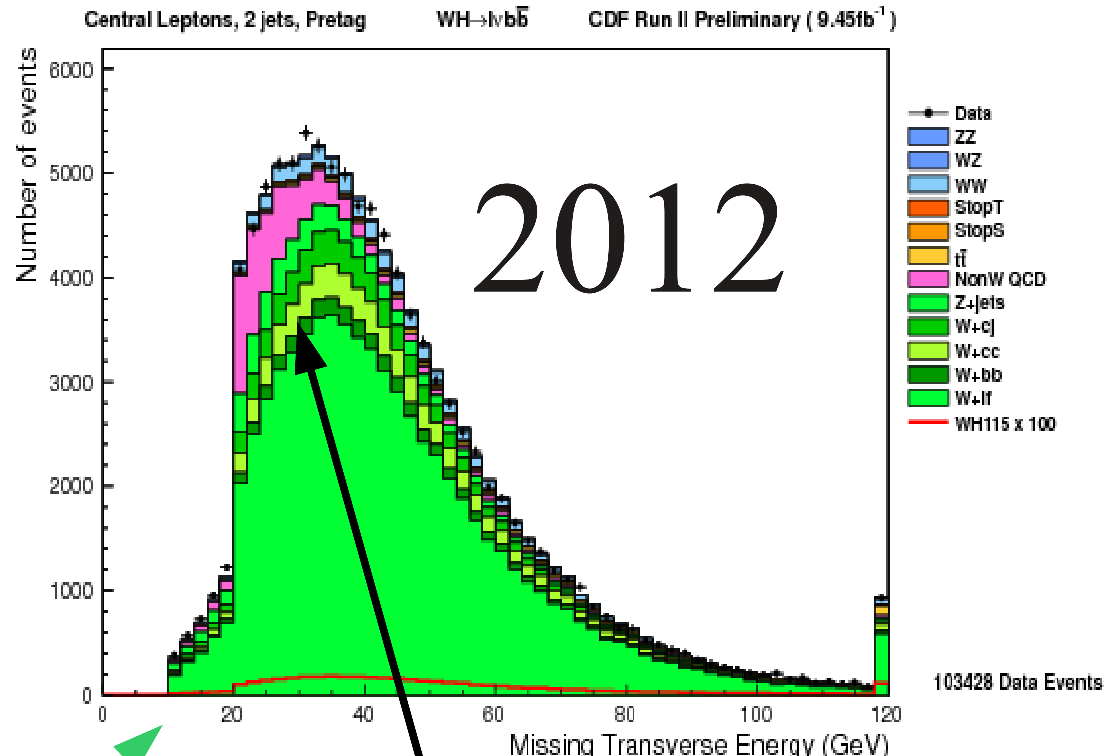






More Acceptance, Same Background

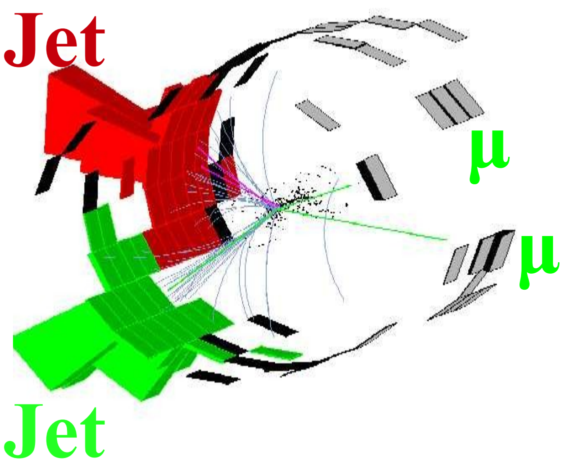


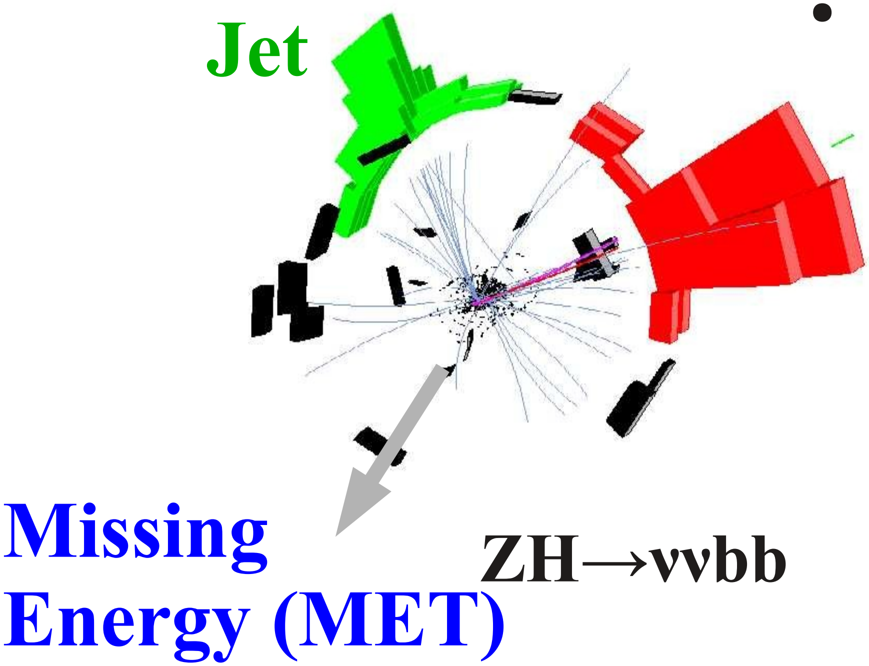


- Use multivariate rejection of **instrumental bkgds**
- Use looser kinematic selections for more pure samples (muons)

More Trigger Acceptance

ZH→μμbb

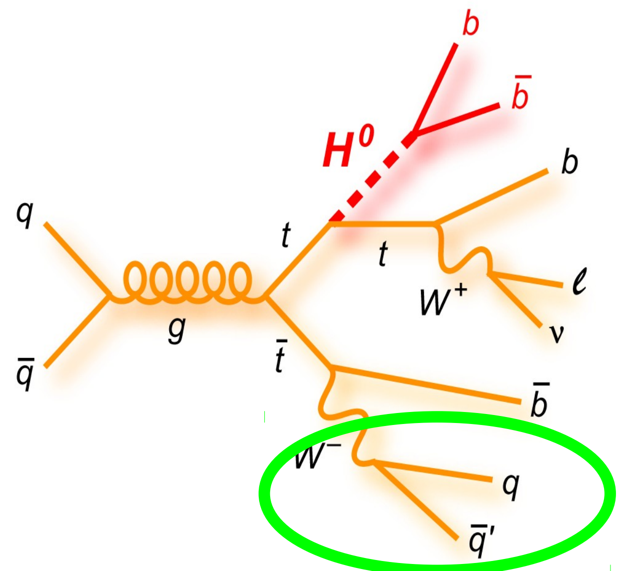




- Data Driven Multivariate Triggers
  - Use Multiple Triggers in **MASSIVE LOGICAL OR**
  - MET, Jets, tracks, Jet+MET, Lepton+MET......
    - **ZH uses EVERY Lepton/MET trigger**
  - Method:
    - Select events in orthogonal sets: A, B, C, D...
    - Use NN to regress on p(A|B), p(A|C)....
      - NN output becomes weight
    - Automatically handles collider, detector time variations.
    - Requires negligible personpower

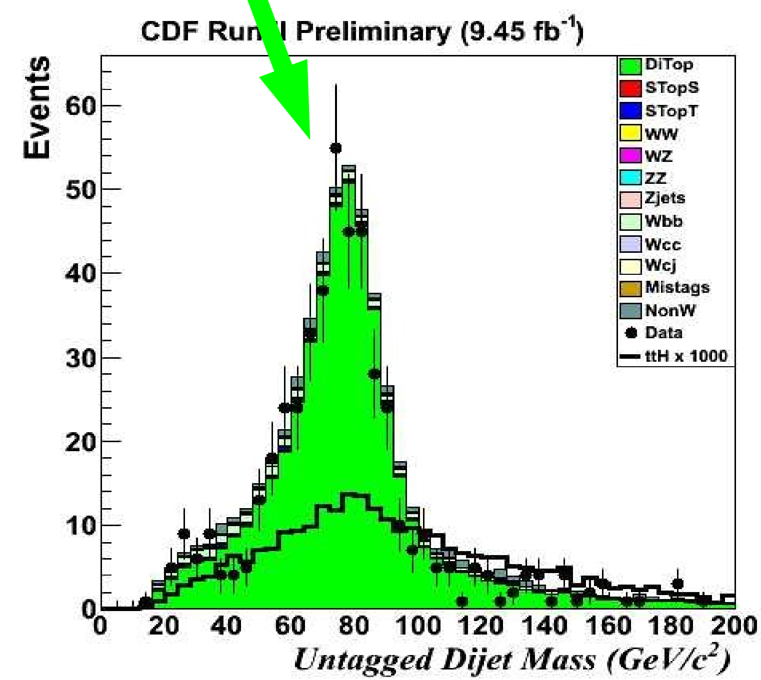
Jet Identification

- Towers clustered with a modified cone algorithm
  - Cone R=0.4
- Calibrated via Z+j, γ+j, dijet balancing
  - Linearity
  - Out-of-cone
  - Underlying event
  - Residual JES uncertainty: ~5%
- Additional resolution improvements
  - CDF: In-situ Z+jj+MET → Z+jj
  - **Smearing of Mjj 10-20%**



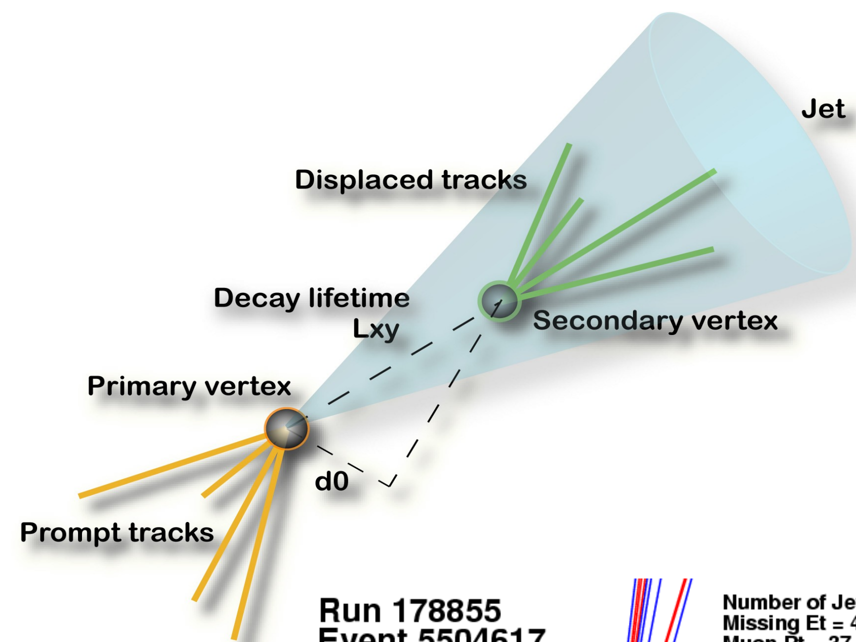
Hadronic W Decays

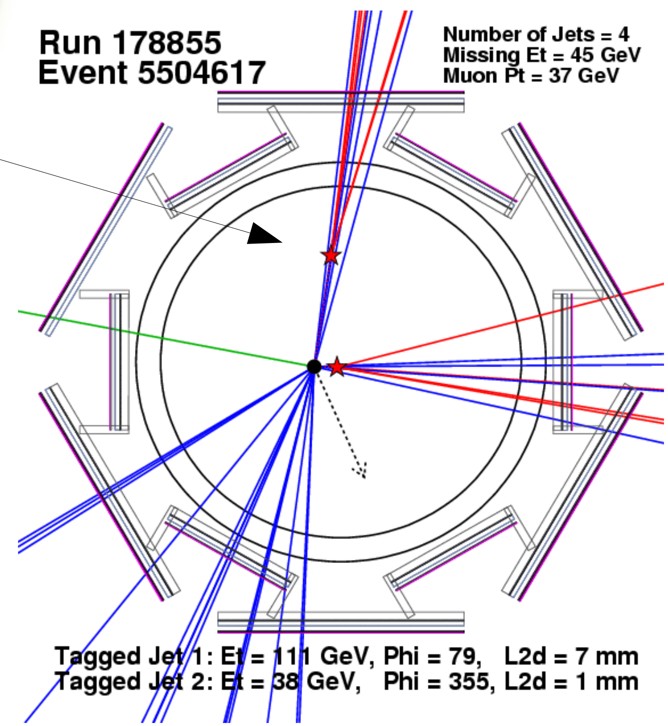
CDF l+MET+jj +bb



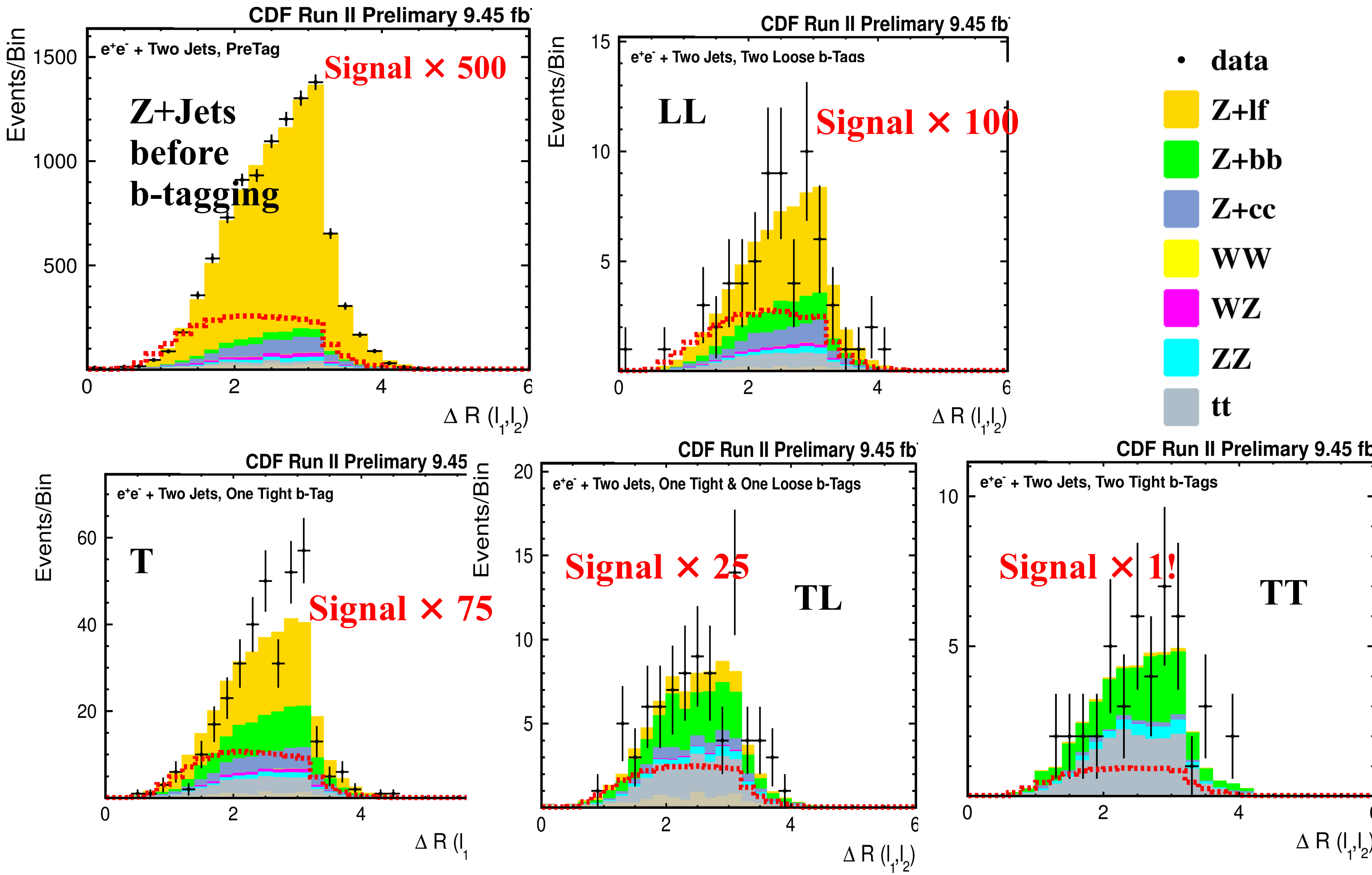
Identifying b-jets

- The mean lifetime of b-mesons is ~1ps
- b-hadrons produced in collisions can travel ~mm before decaying
- Jets with secondary decay vertexes, or with single tracks significantly displaced from the beamline are "tagged"
- Charm-meson and mis-reconstructed u,d,s,c,g jets are a background

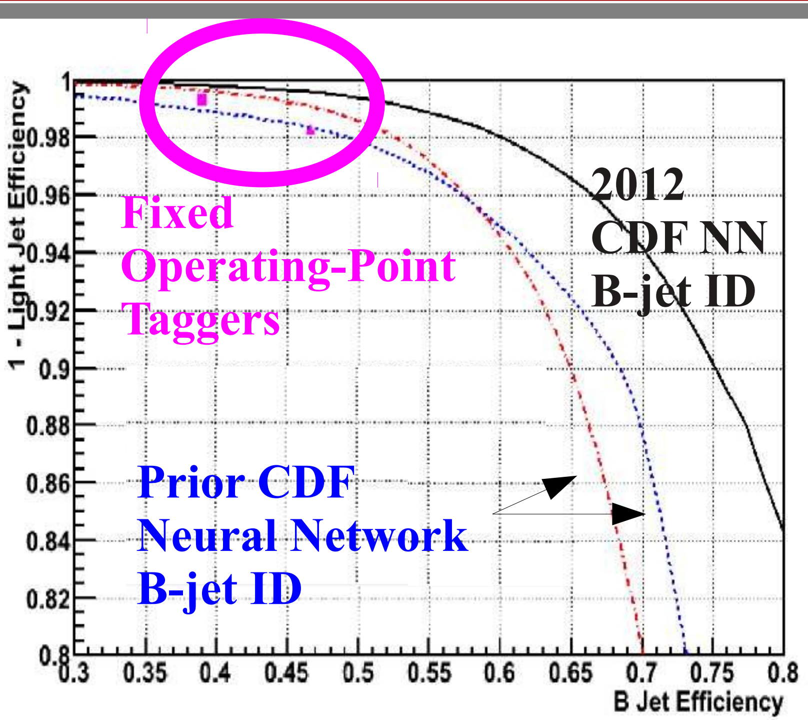


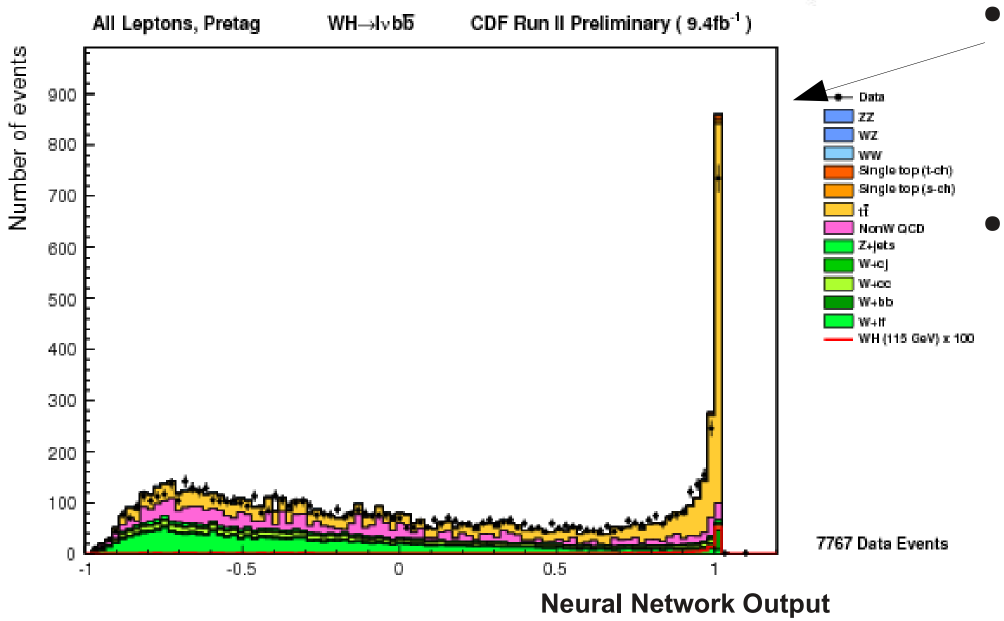


B-Tagging for Signal Significance



Improved b-Tagging

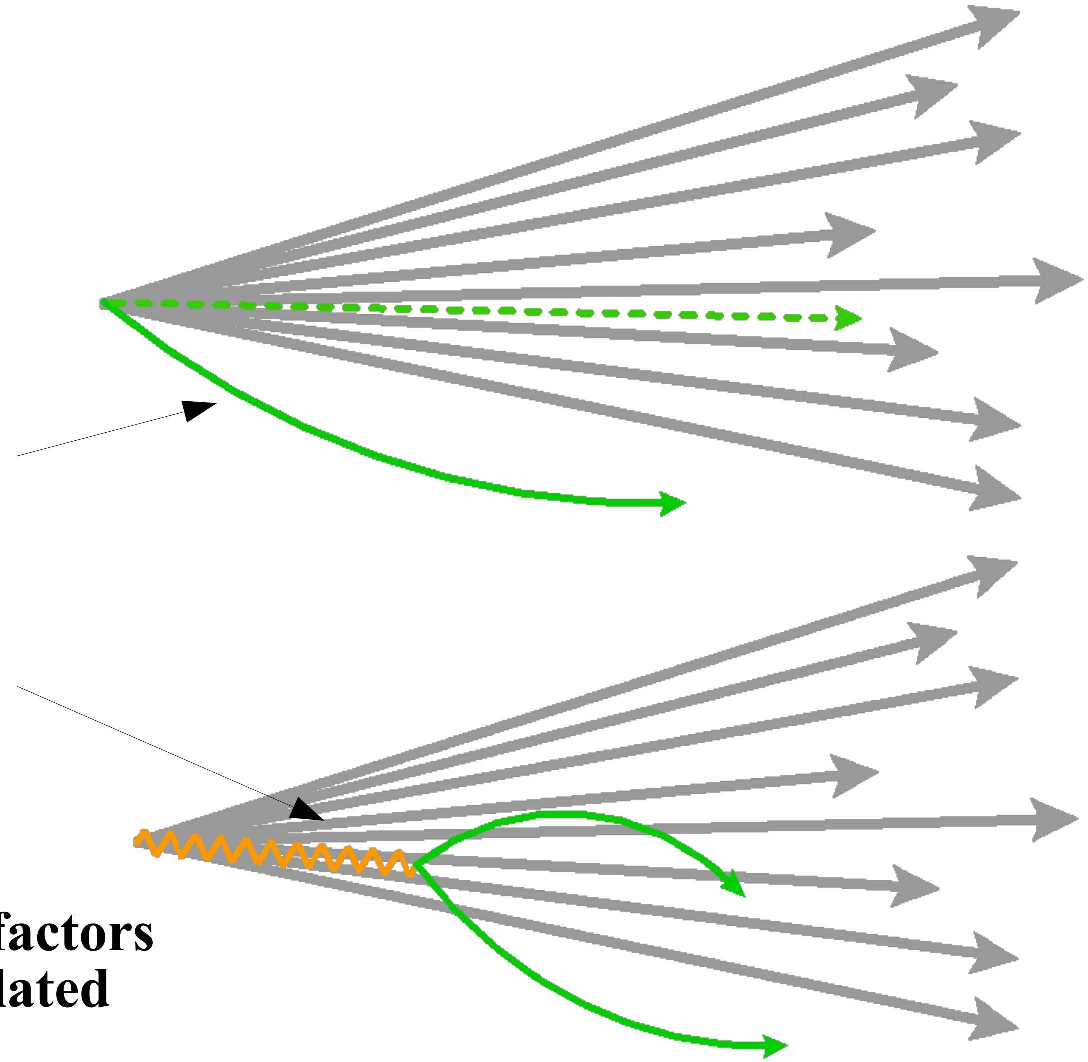




- 2011: CDF WH (ZH,VH) used 3 (2) different b-taggers in orthogonal series
- 2012: New CDF Neural Network b-tagger
  - Uses most sensitive variables from previous CDF taggers
    - Uses semileptonic b-decay muons, Jet tower Mass, secondary vertex mass...
    - Can tag single-track jets
  - Continuous variable output allows for analysis group to choose cuts:
    - optimize expected sensitivity
  - Bottom line:
    - ~10% higher integrated s/√b:
    - ~10% stronger upper CL.

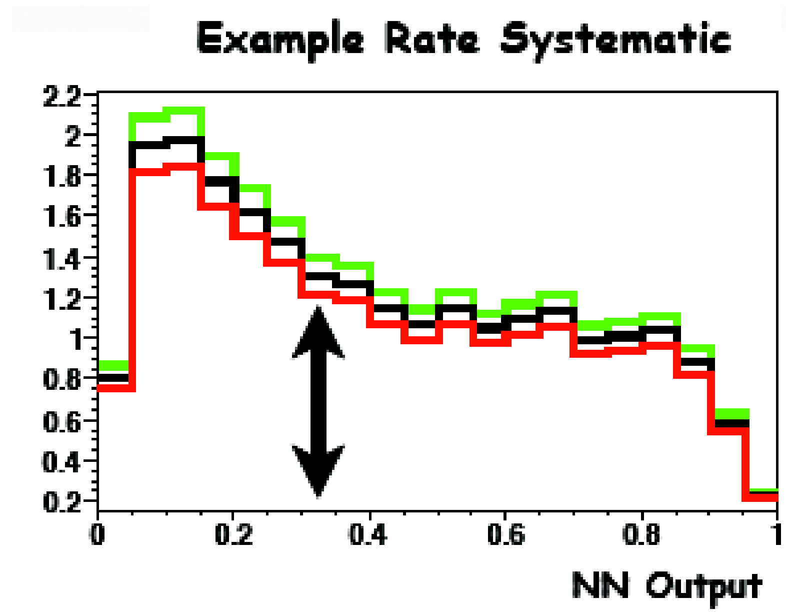
Calibration of 2012 b-Jet Tagger In Multiple Control Samples

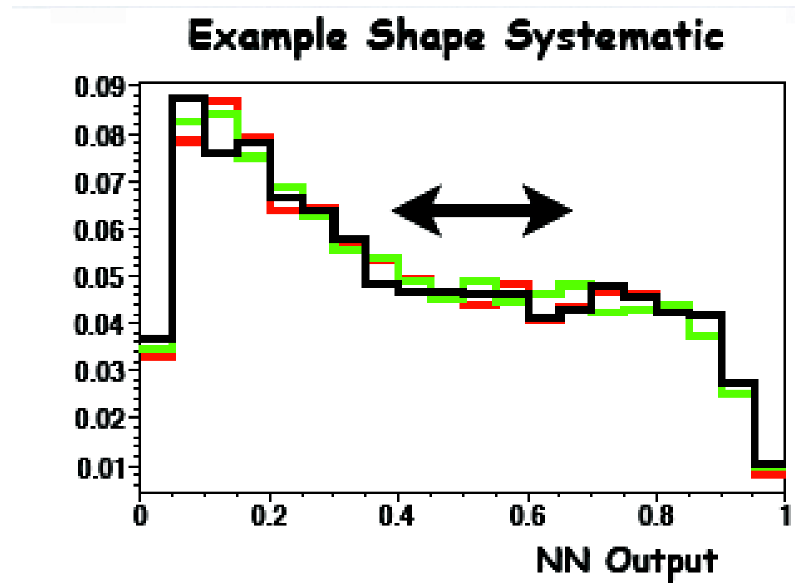
- Calibration samples
  - Kinematic selection of W+4,5 jets events (di-top)
  - QCD dijets with low relative-pt electrons
    - Not an input to tagger
    - Semileptonic decay electrons
      - Enriched in b,c
    - Photon conversion electrons (New Method)
      - Primarily u,d,s,c,g
    - Examine both e-jet and opposing side jets
- These samples produce correction factors and uncertainty estimates for simulated events
- Resulting b-jet tag-rate corrections: ~5%±4%



Dominant Uncertainties

- Uncertatinties degrade exclusion sensitivities by ~20%
- Experimental
  - Jet energy scale (shape)
    - Vary simulated reconstructed energies
  - Luminosity
  - B-jet ID simulation
  - Lepton ID/veto
- Theoretical
  - Cross section uncertainties, K-factors
    - ~1.5 for W+jets, Z+jets
    - Extra heavy-flavor K-factor ~1.5
  - Renorm/Factorization scale (shape)
    - Vary renormalization / factorization scales
  - PDF
  - Initial/final state QCD radiation (shape)
    - Vary QCD showering parameters in simulation

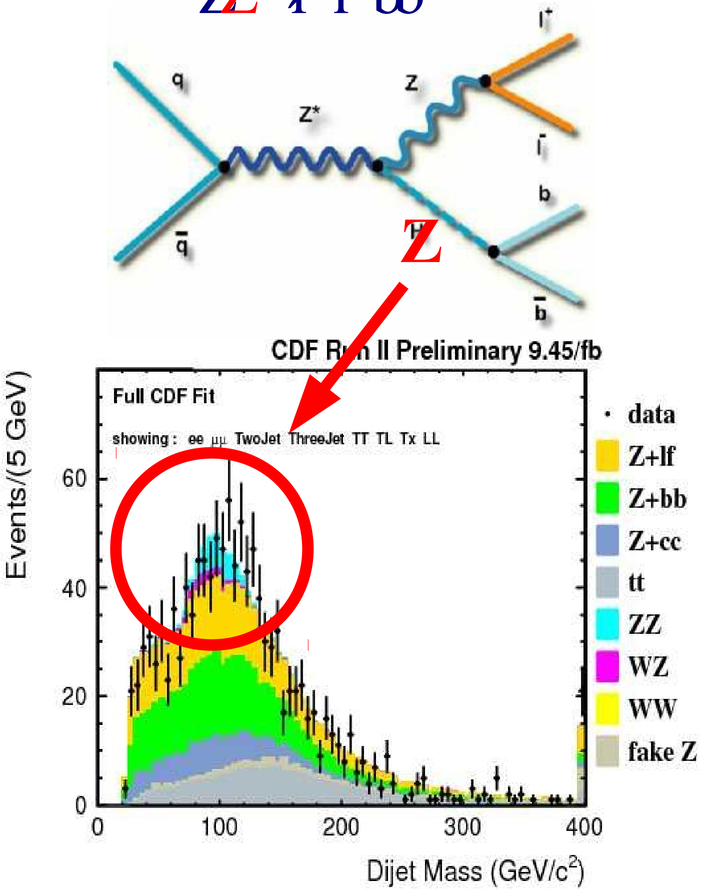




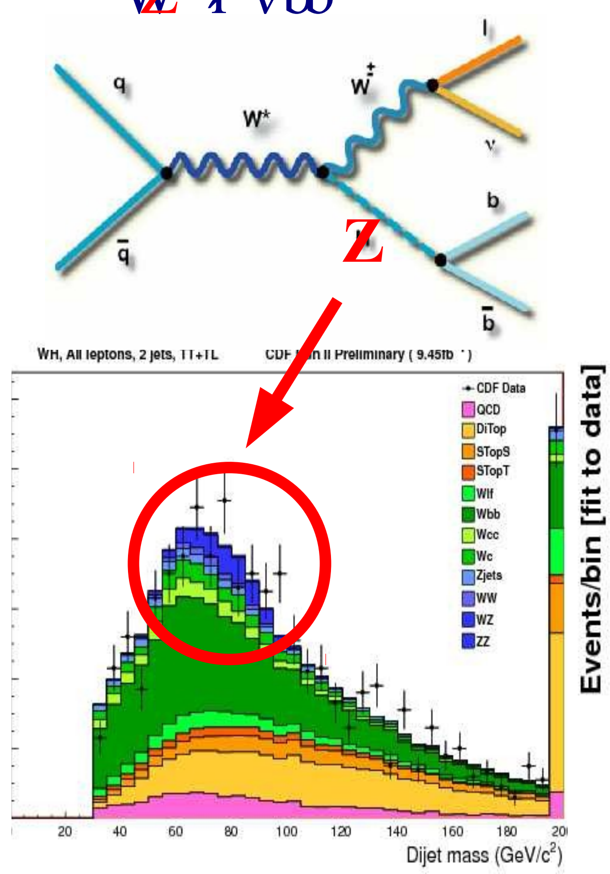
WZ+ZZ: Validating Methods

- Standard candle: WZ+ZZ
  - Search methods identical to WH+ZH

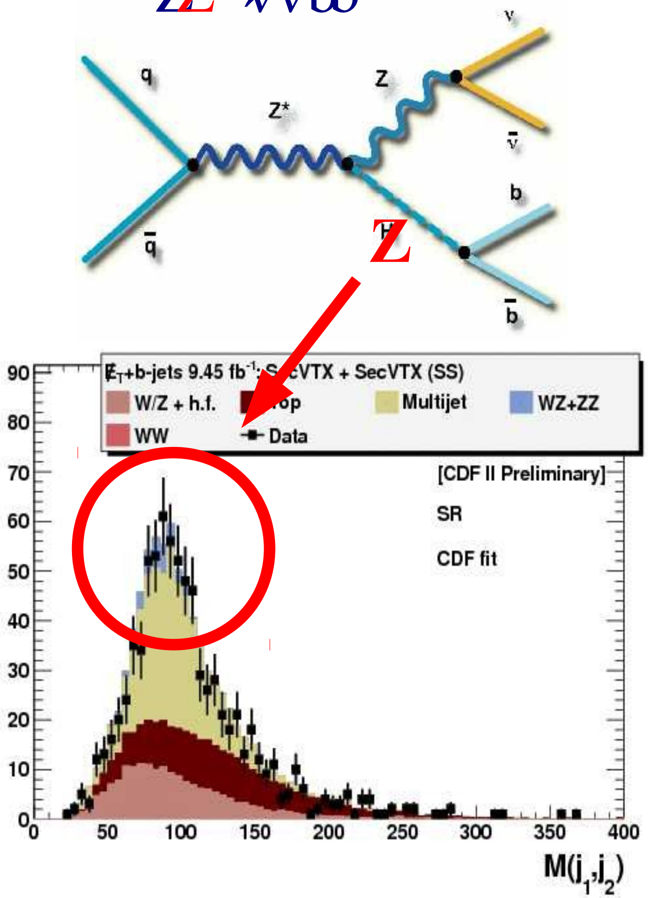
$ZZ \to l^+l^-b\bar{b}$



$WZ \to l^{\pm}\nu b\bar{b}$

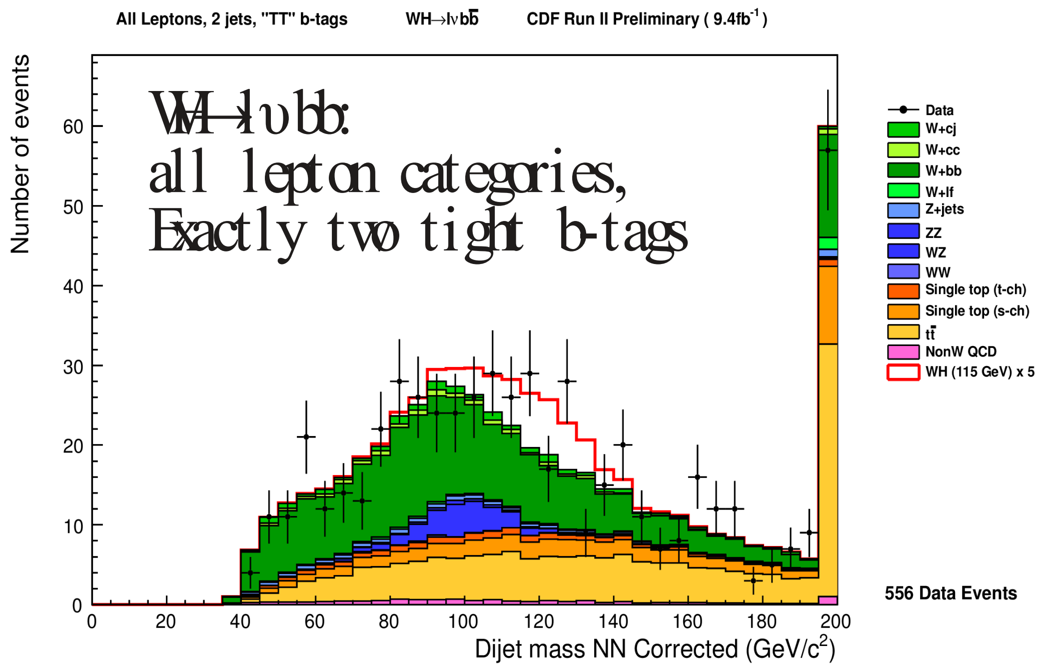


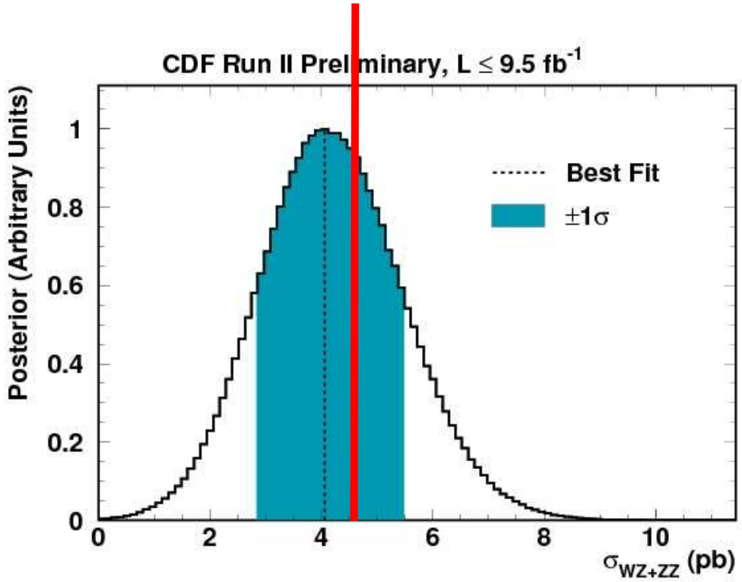
$ZZ \to \nu\bar{\nu}b\bar{b}$



WZ+ZZ: Validating Methods

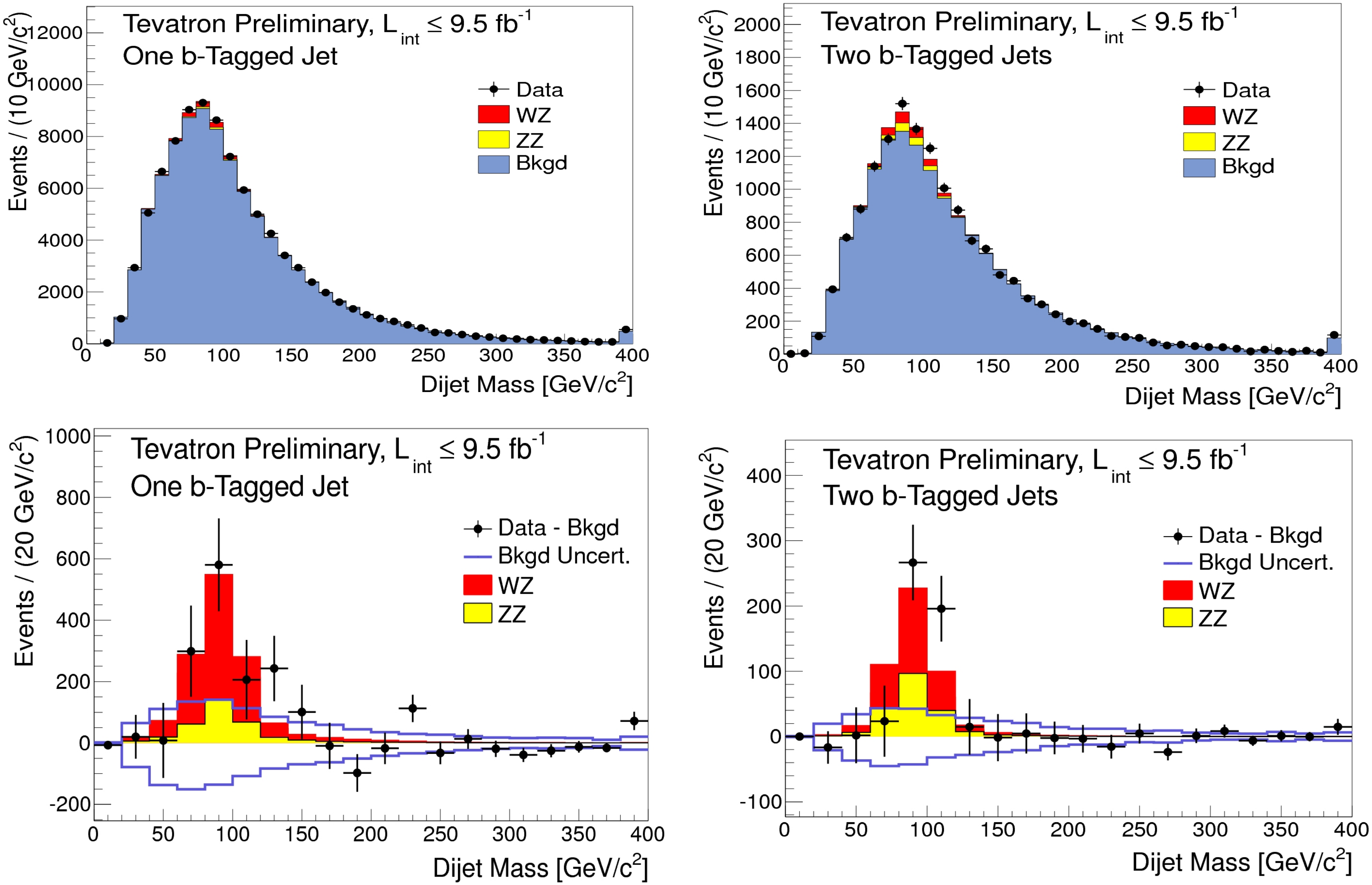
- **Search for Z→bb in llbb, lυbb, υυbb**
  - Identical final state as a "90 GeV Higgs"
- **CDF SM expected yields for WH,ZH,VH: (Summed over all subchannels)**
  - ~215 WZ+ZZ
  - ~591 H→bb (MH=90)
  - ~84 H→bb (MH=125)
- **Measured cross section compared to NLO**
  - SM * 0.92 + 0.31 – 0.28
  - significance of ~3.2 sigma
- **DØ also sees SM-compatible VV**
  - 3.28 sigma significance





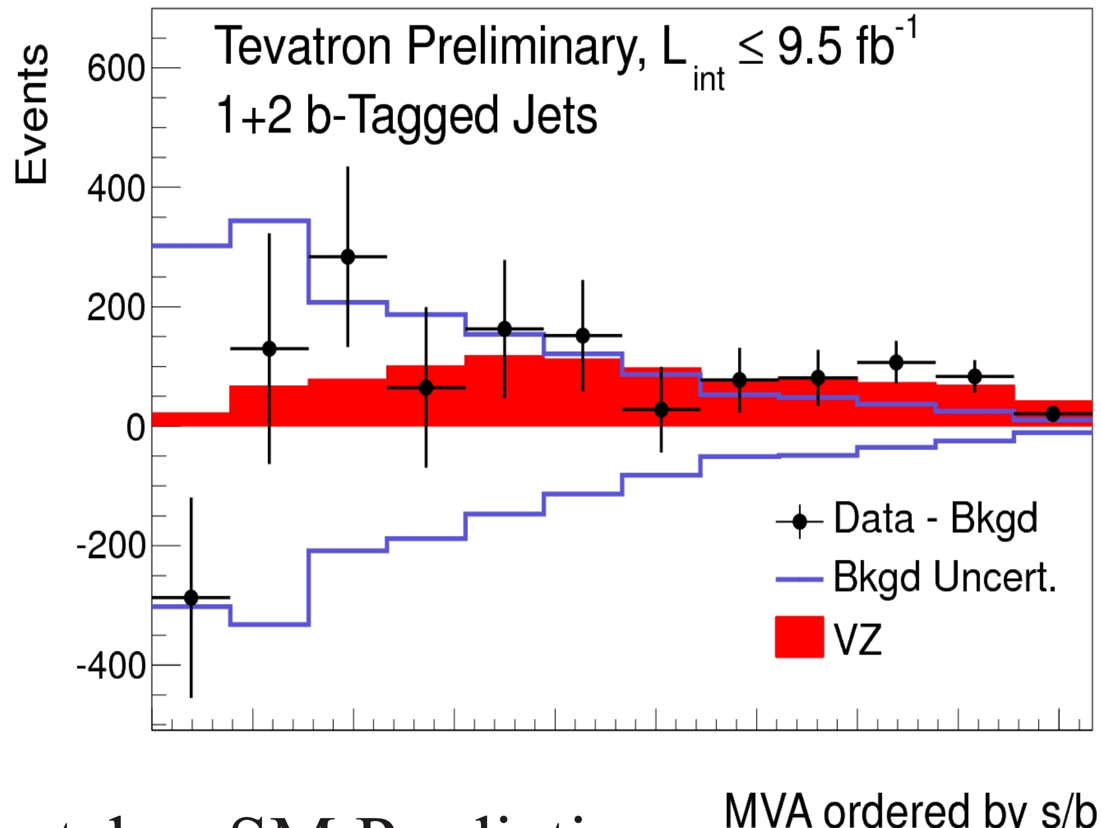
WZ+ZZ: Validating Methods

- **Tevatron Combined Dijet Mass Spectra**



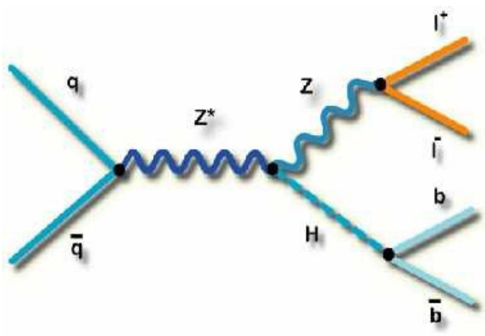
WZ+ZZ: Validating Methods

- Discriminants trained for WZ+ZZ, just like in Higgs Search
- Right plot shows signal ordered, rebinned, combined discriminant
- Good agreement within systematics
- Signal above systematics in rightmost region
- 4.6 sigma significance
- Measured cross section matches SM Prediction

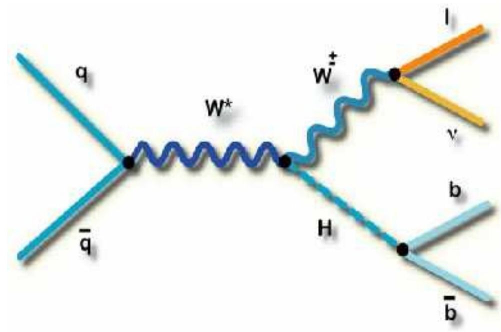


Associated Production Channels

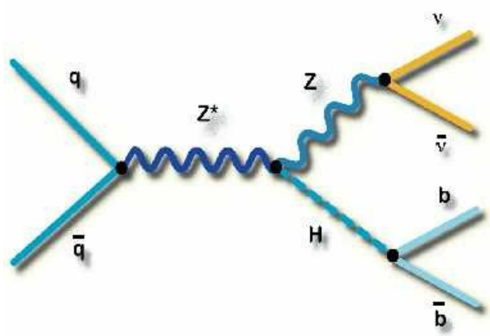
$ZH \to l^+ l^- b\bar{b}$

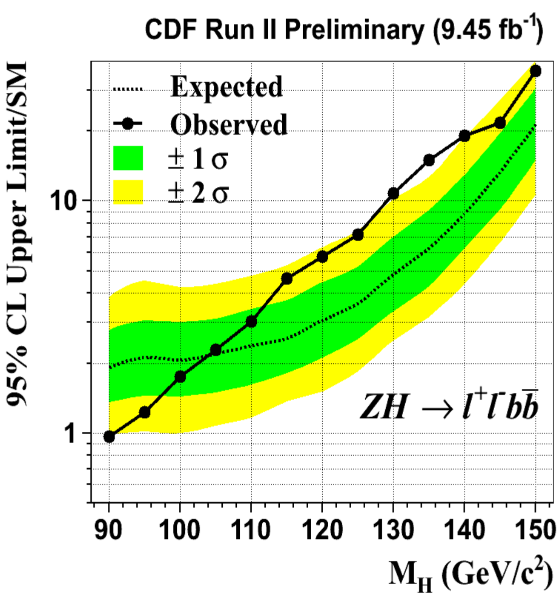


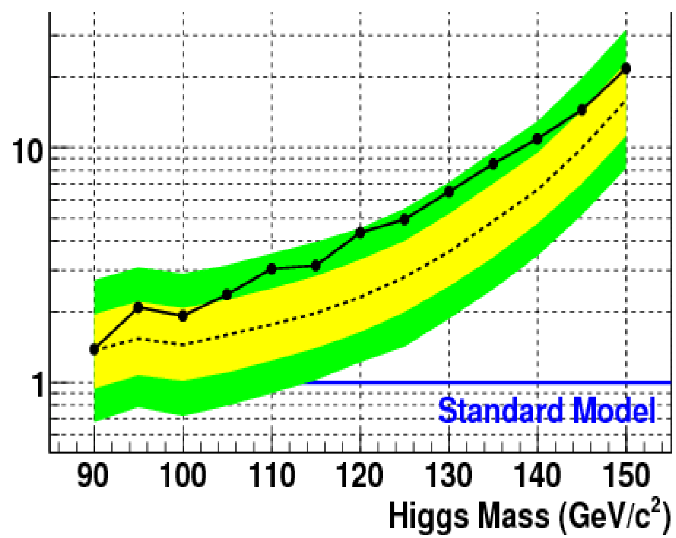
$WH \to l^{\pm} \nu b\bar{b}$

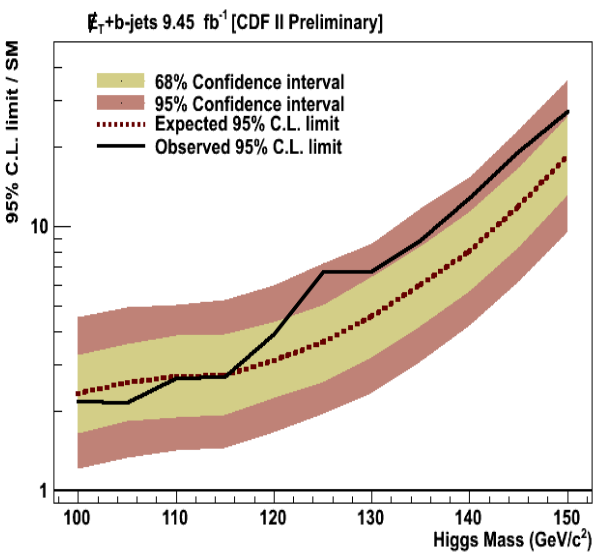


$ZH \to \nu\bar{\nu} b\bar{b}$

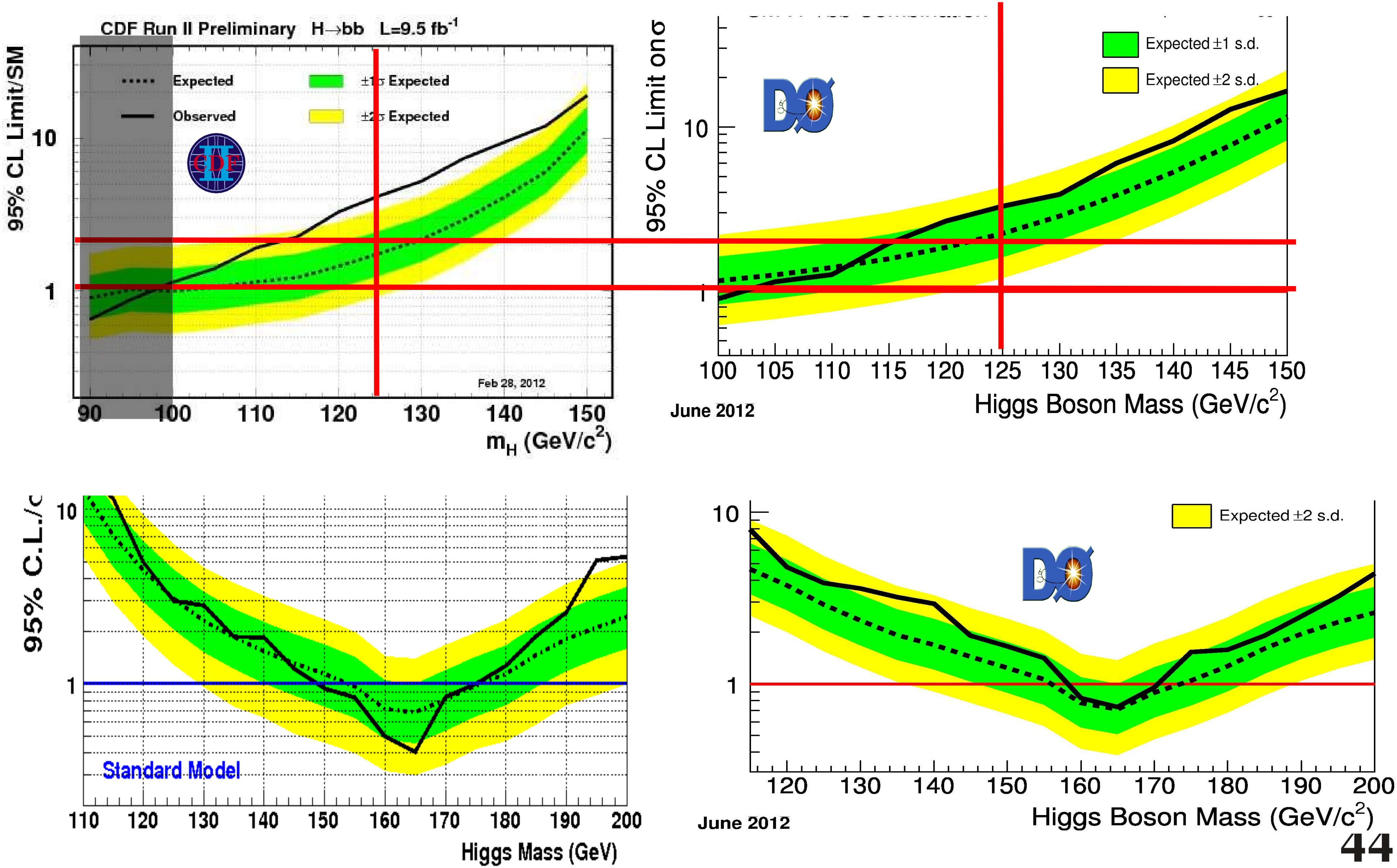






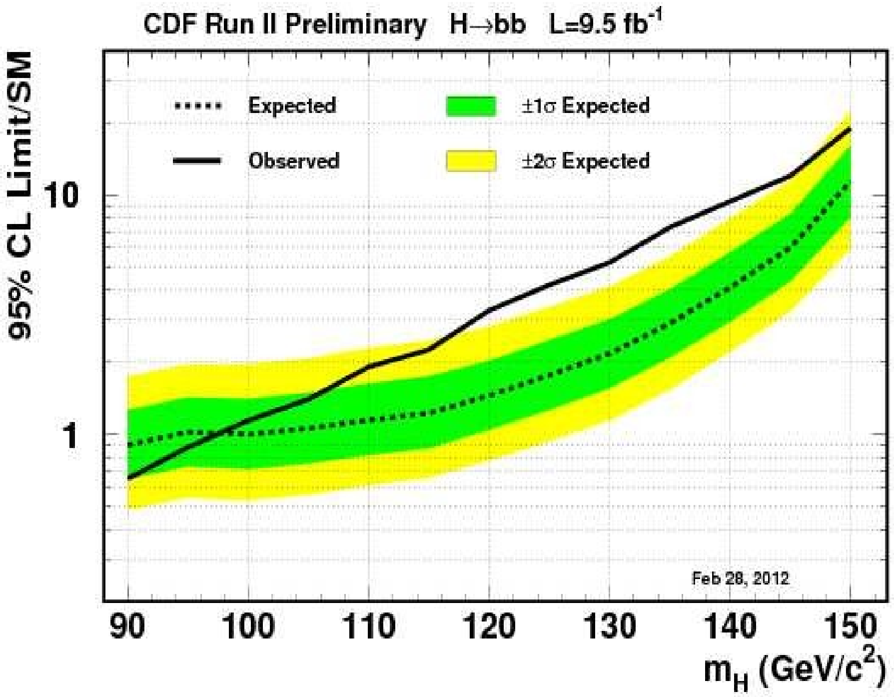


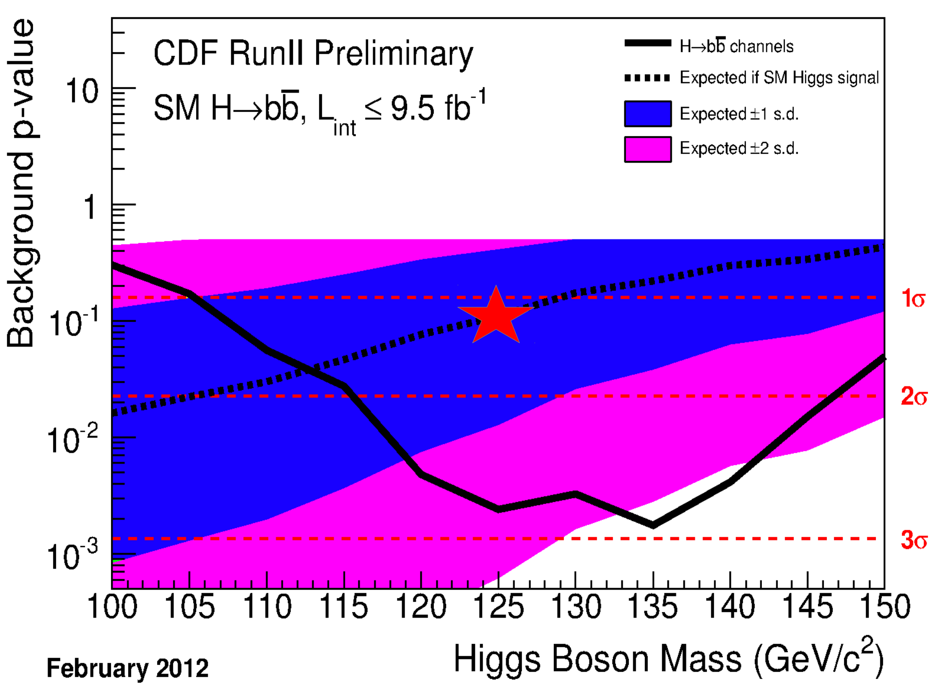
WW, bb Combined Searches For CDF and DØ



Excess in H→bb

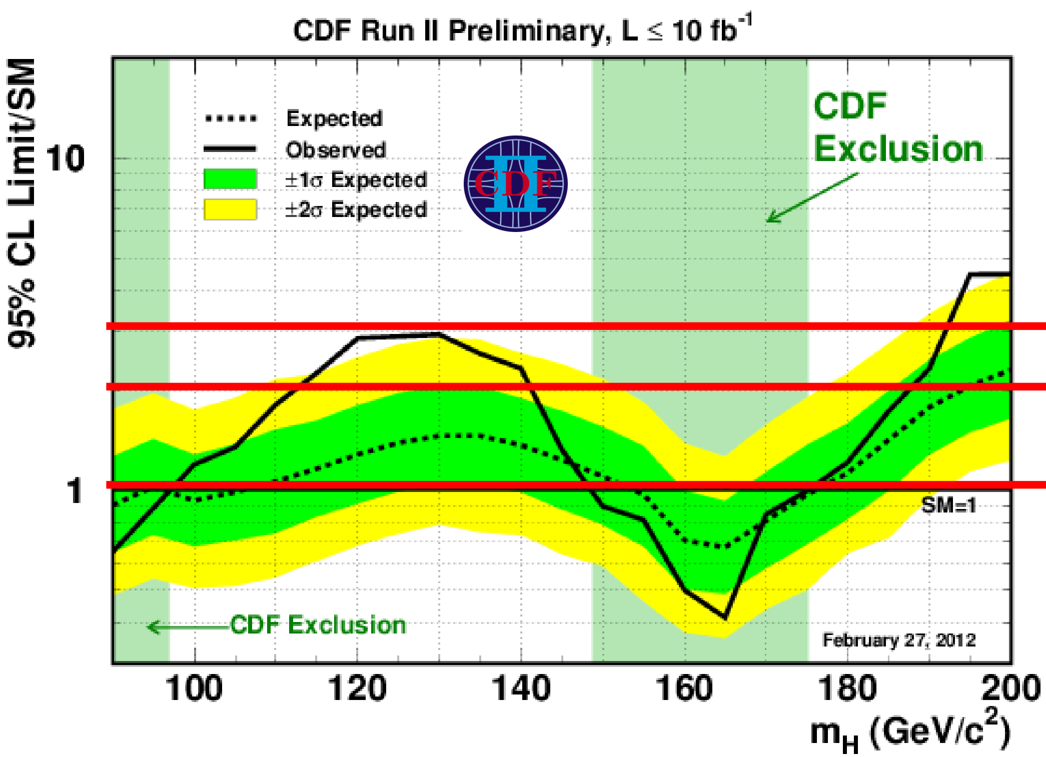
- Clear excess in CDF H→bb decays
- Largest excess is at 135 GeV
- **Not like γγ or ZZ→4l:**
  - **Poor mass resolution→neighboring points correlated**
- Global p-value is 2.7 sigma (Expected Signal ~1.5 sigma)

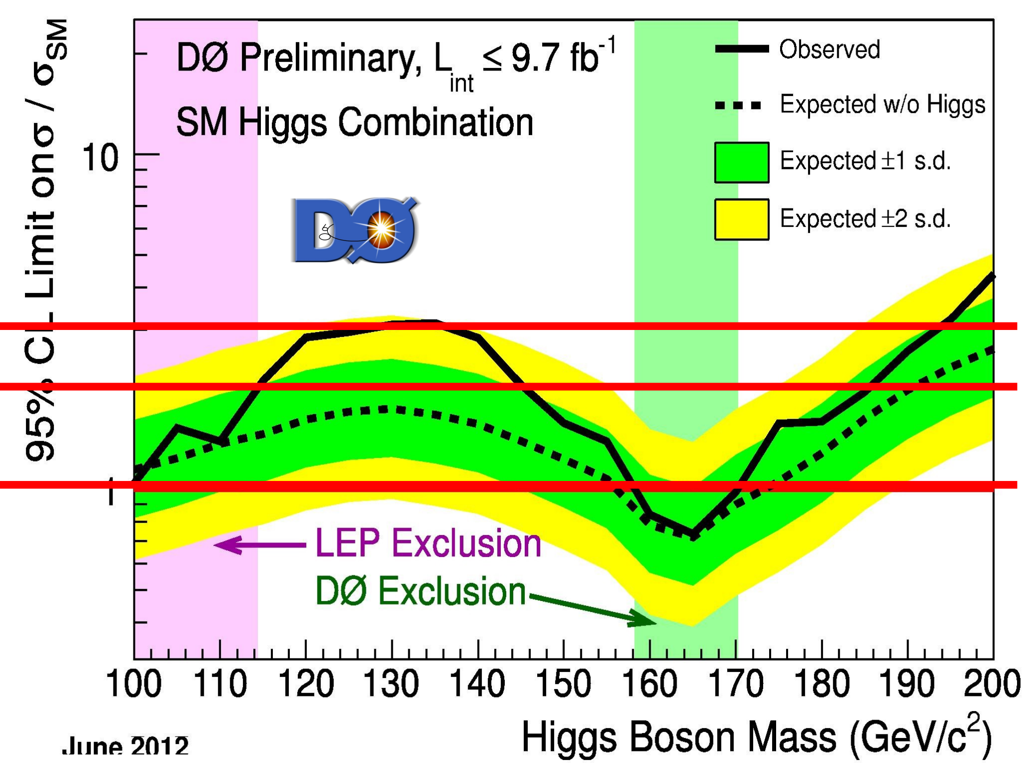




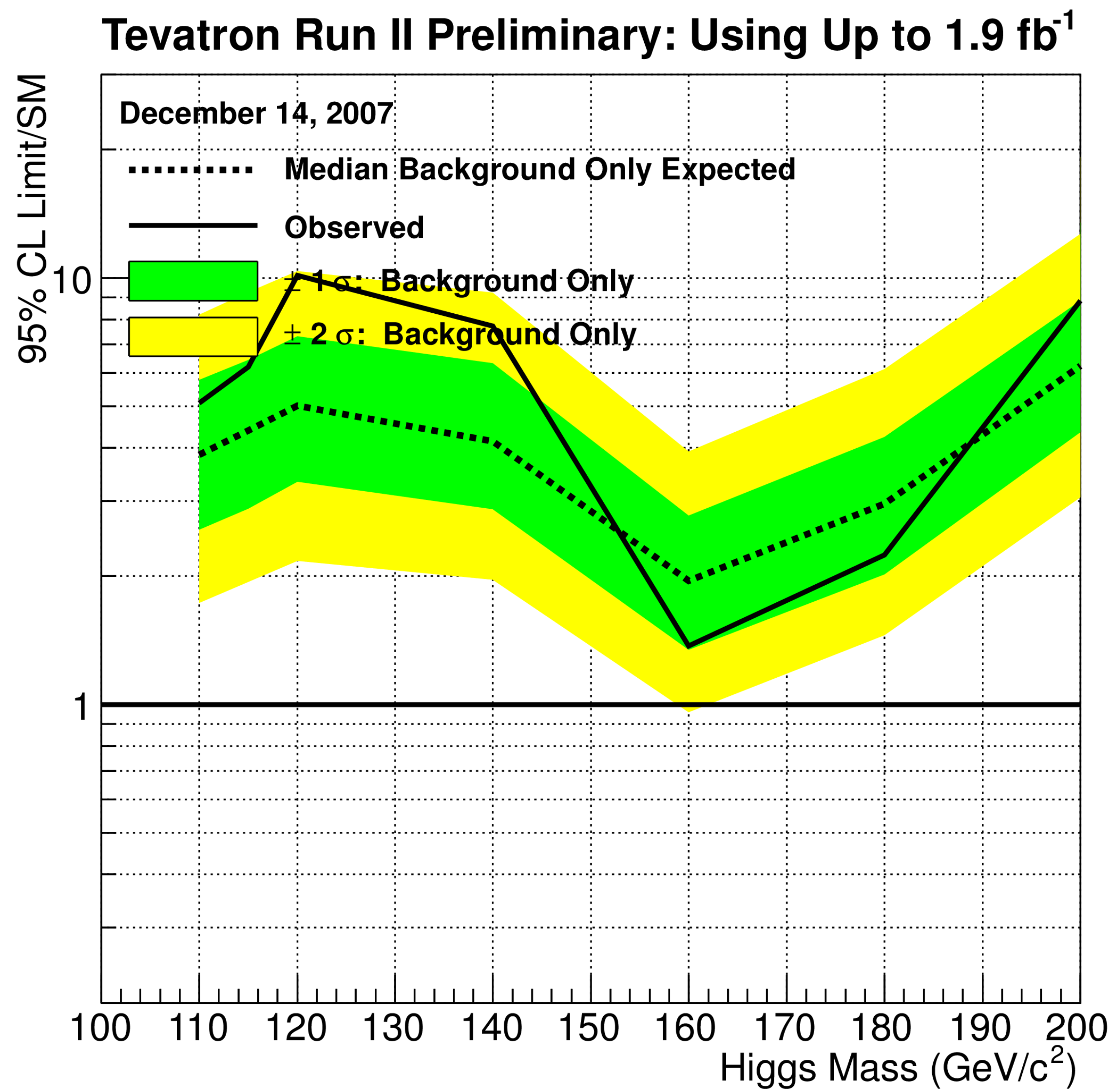
CDF and DØ Combined Searches

- DØ: Exclude 159 < MH < 166 GeV
- CDF: Exclude 147 < MH < 175 GeV
- Both have broad excess 100-150

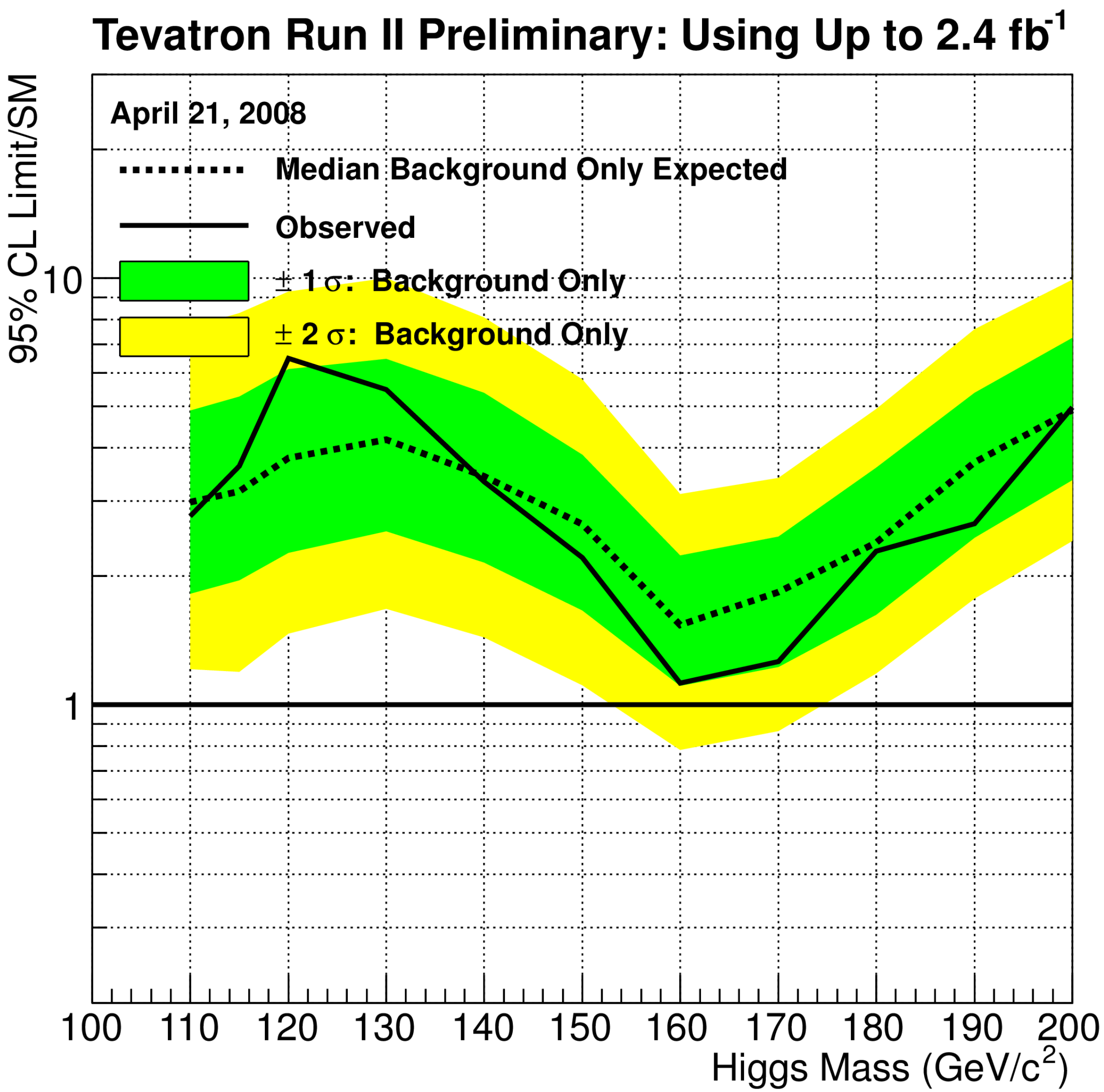




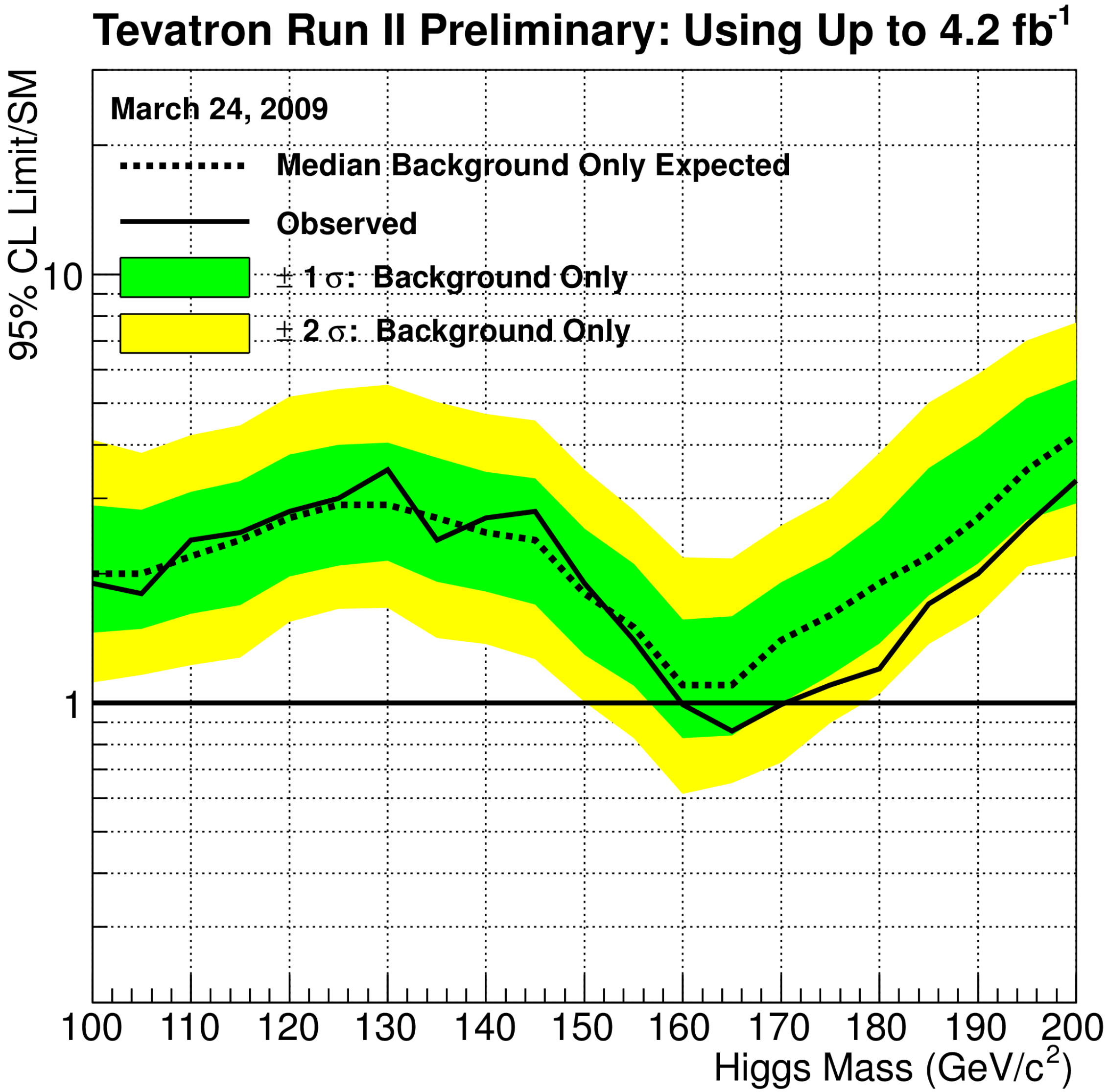
Tevatron Combination Dec. 2007



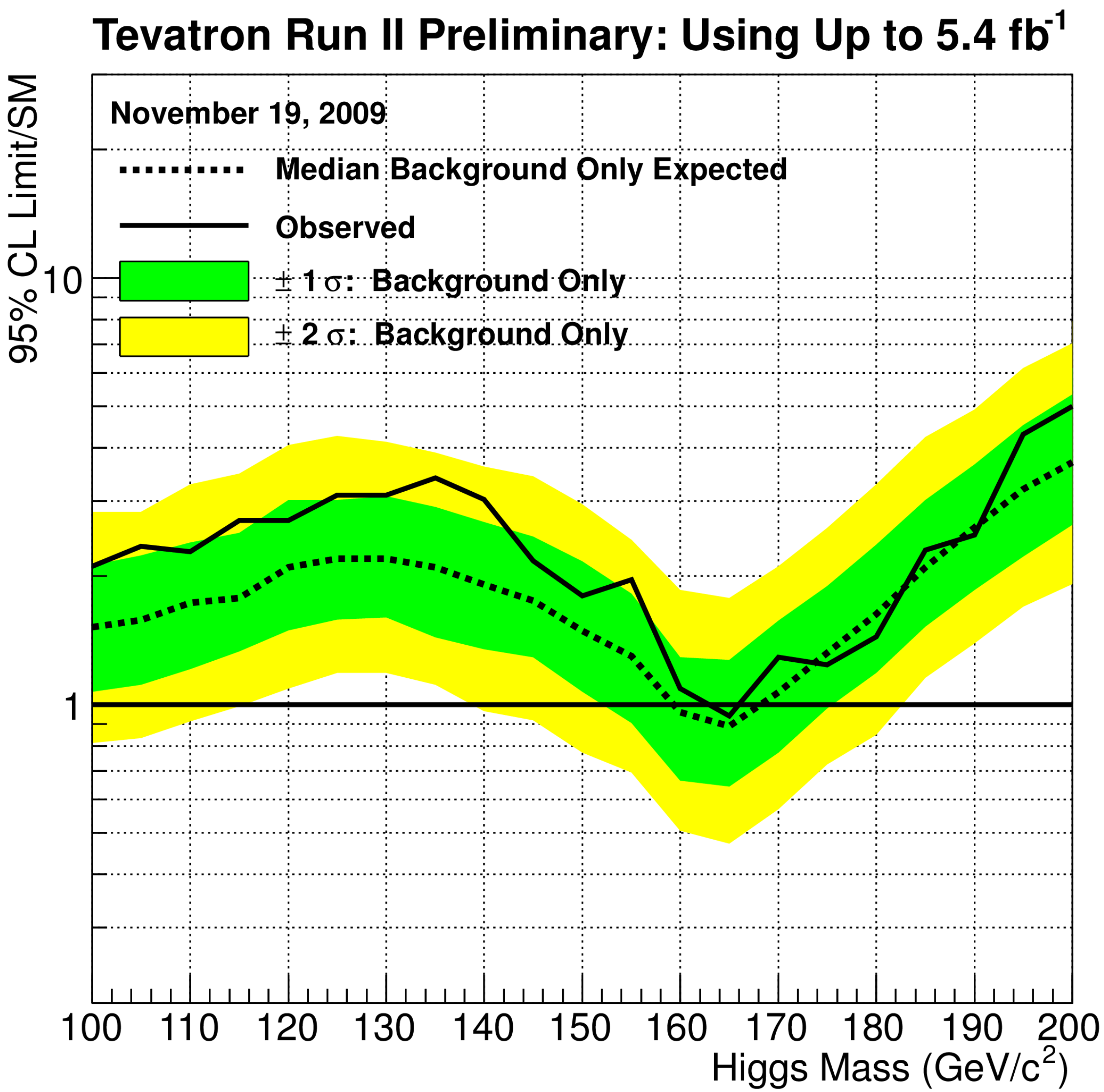
Tevatron Combination Apr. 2008



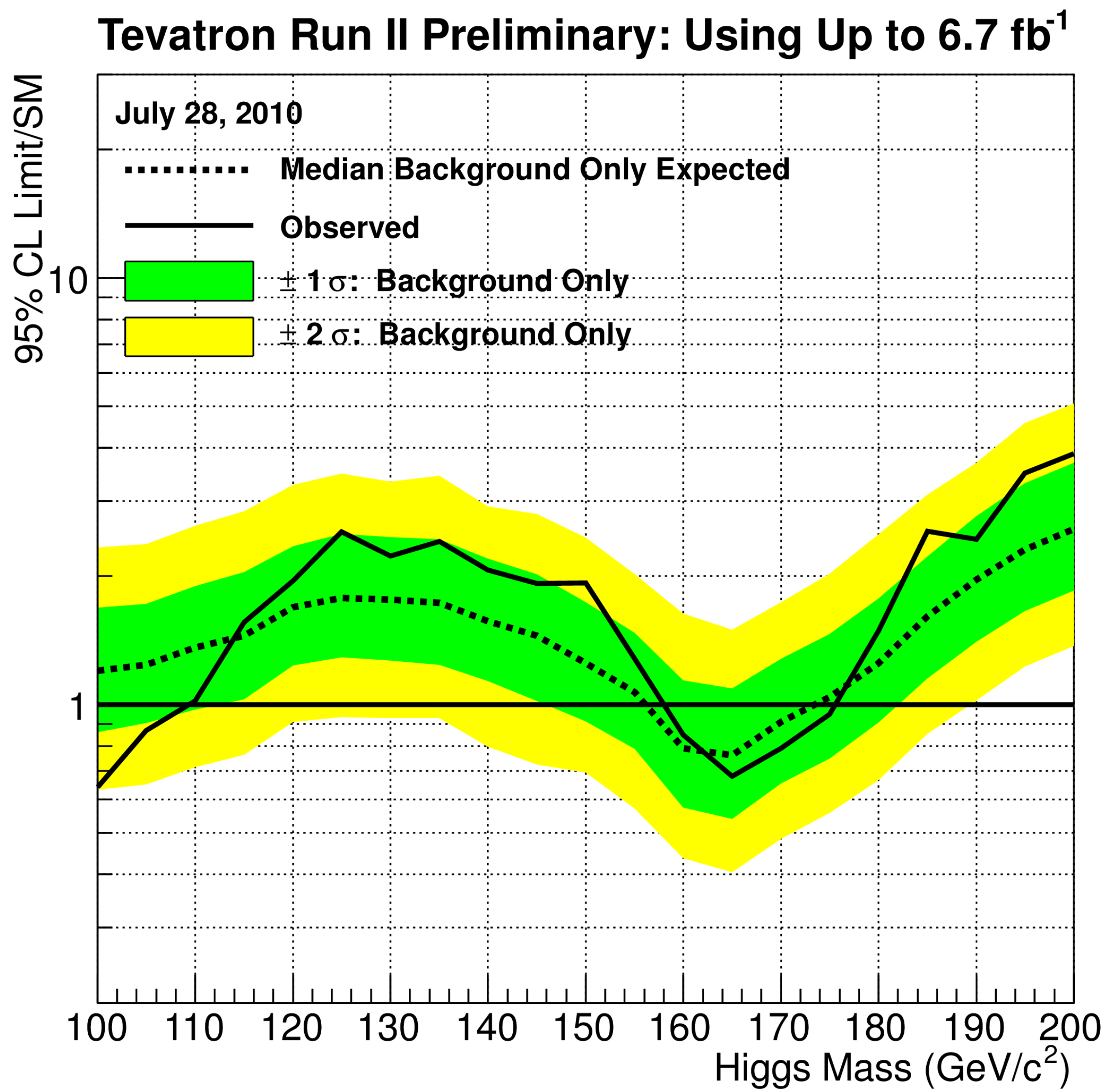
Tevatron Combination Mar. 2009



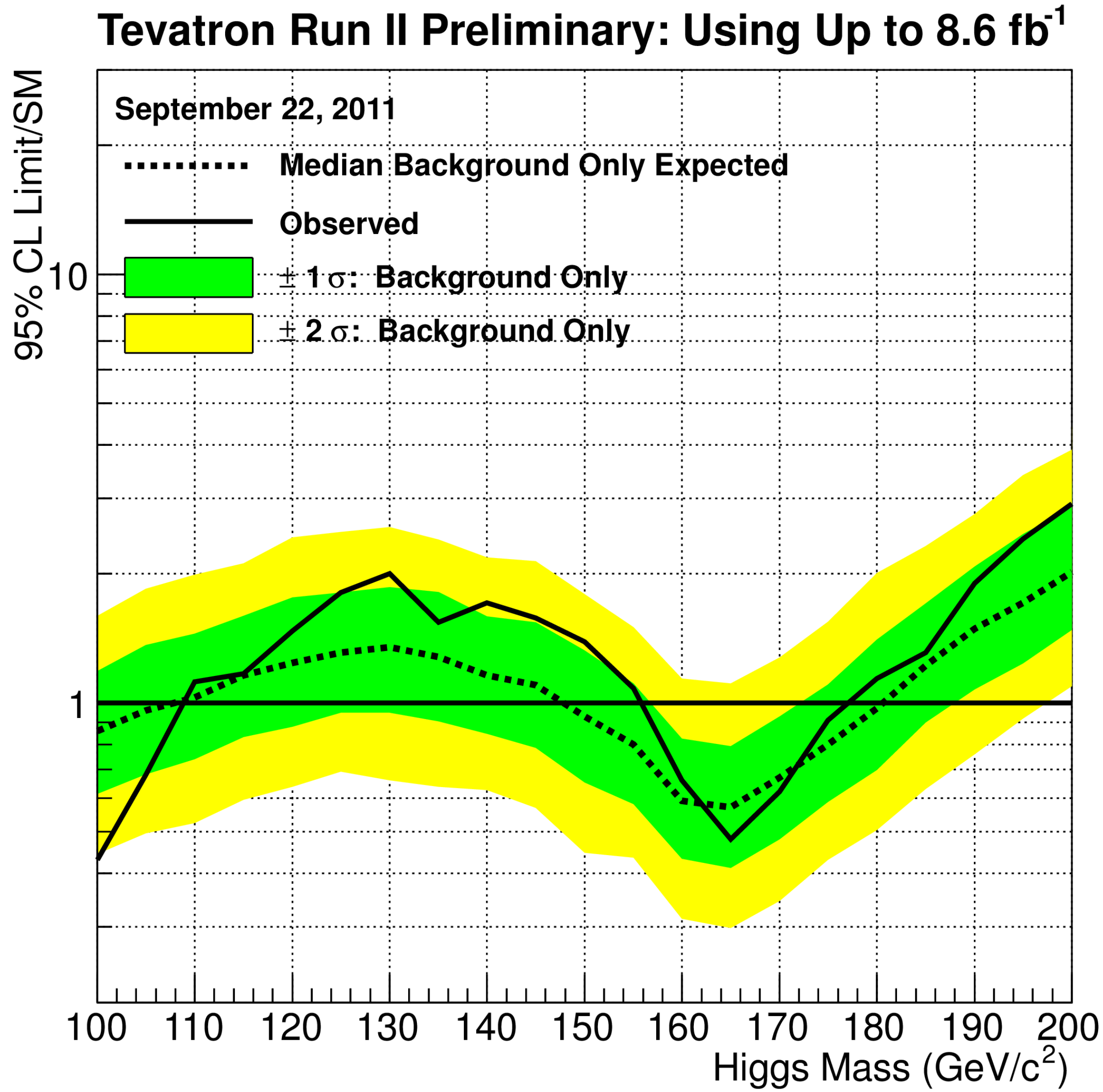
Tevatron Combination Nov. 2009



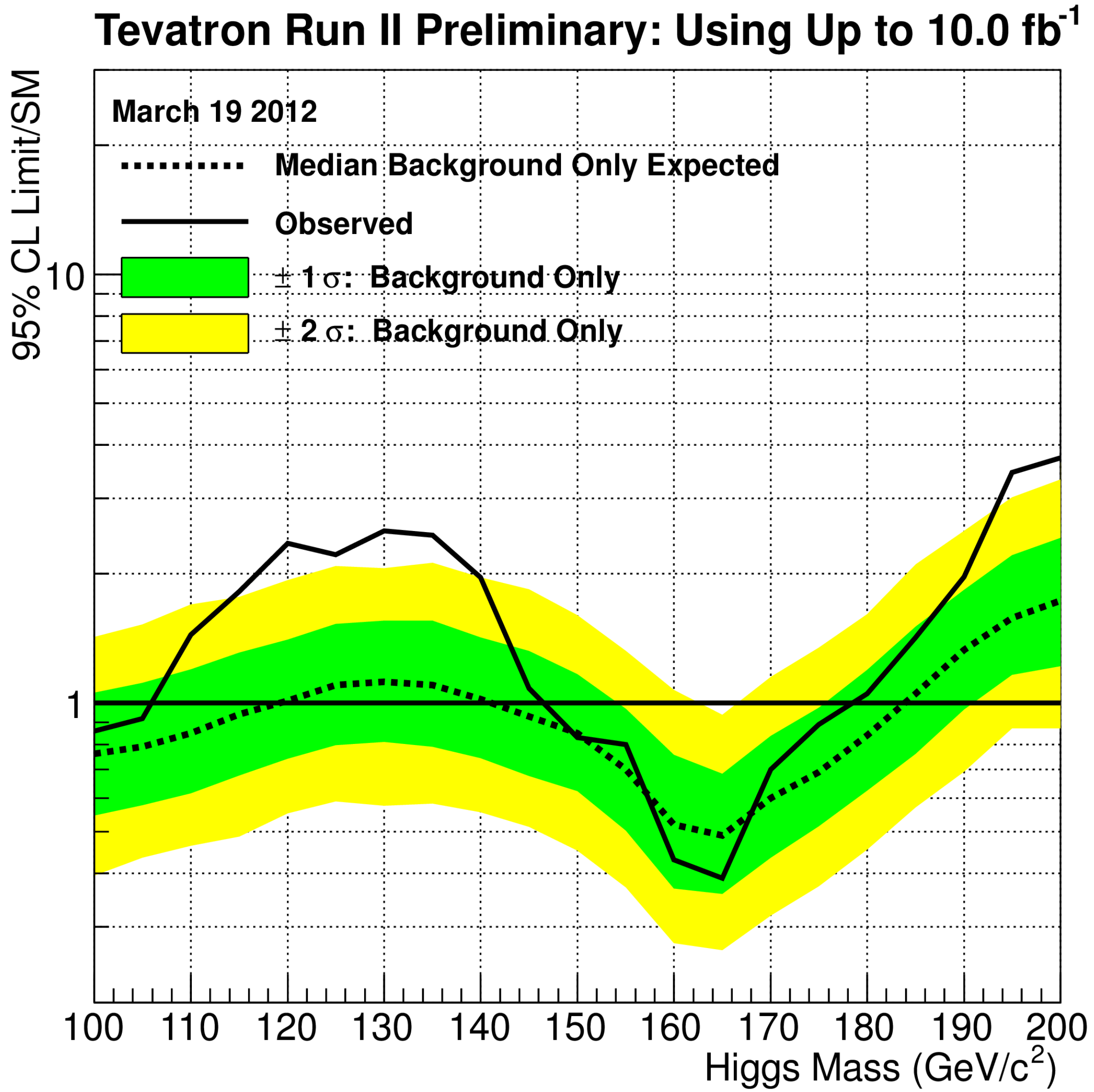
Tevatron Combination July. 2010



Tevatron Combination Sep. 2011

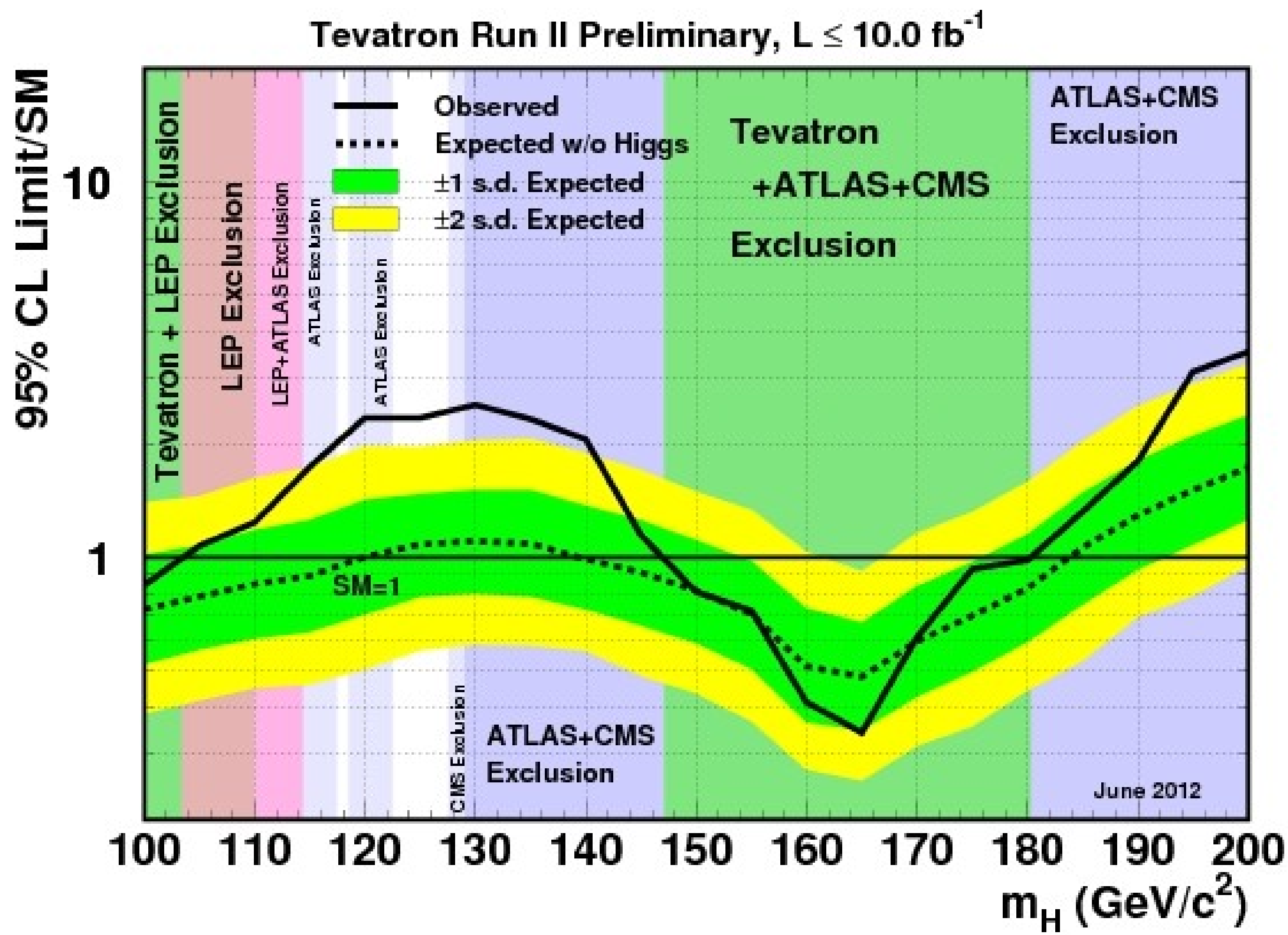


Tevatron Combination Mar. 2012



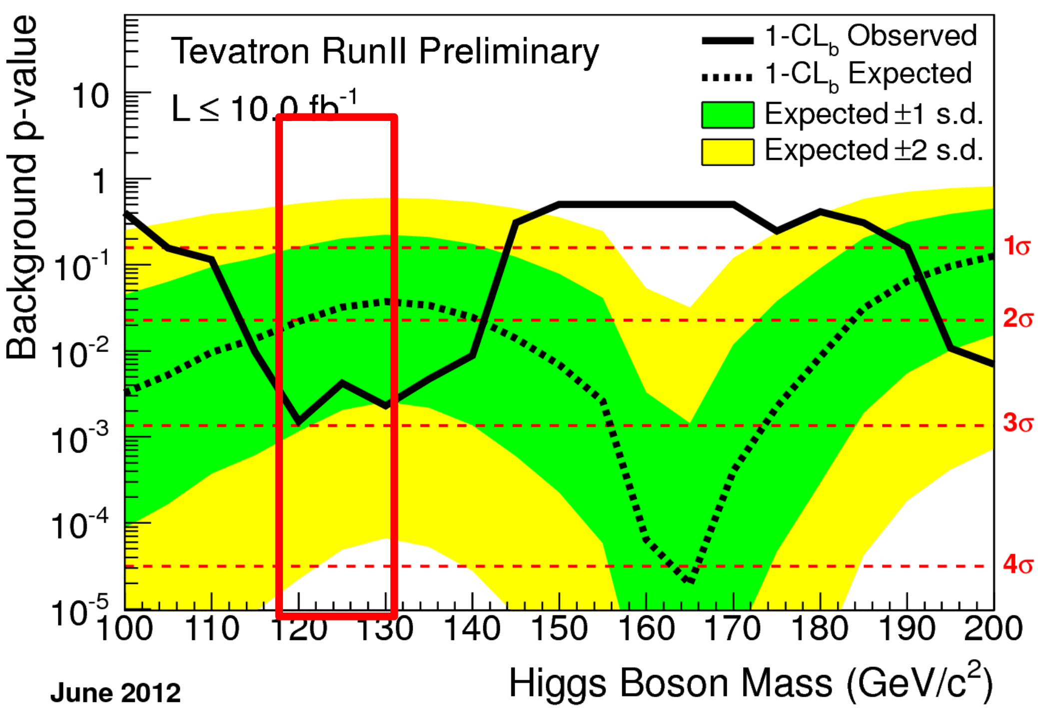
The Winter 2012 Tevatron Combined Higgs Search

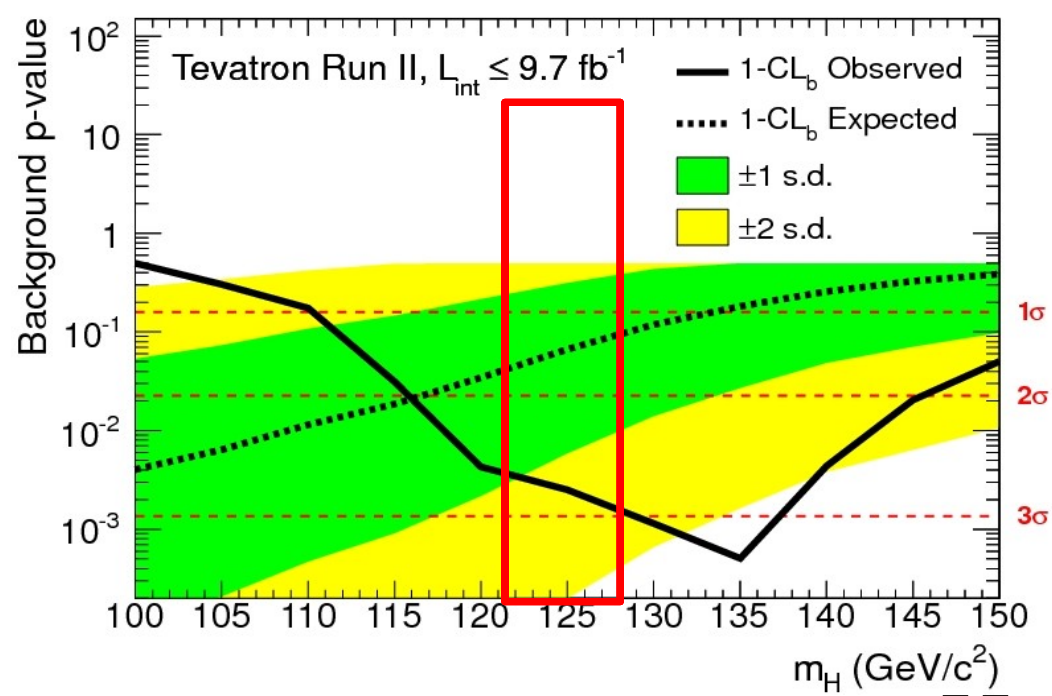
- Expect to exclude nearly everywhere
  - 1.10*SM at 130 GeV
- Exclusion:
  - 100-106 GeV
  - 147-180 GeV
- Broad excesses
  - ~105-145 GeV
  - ~190-200 GeV



Quantifying The Excess

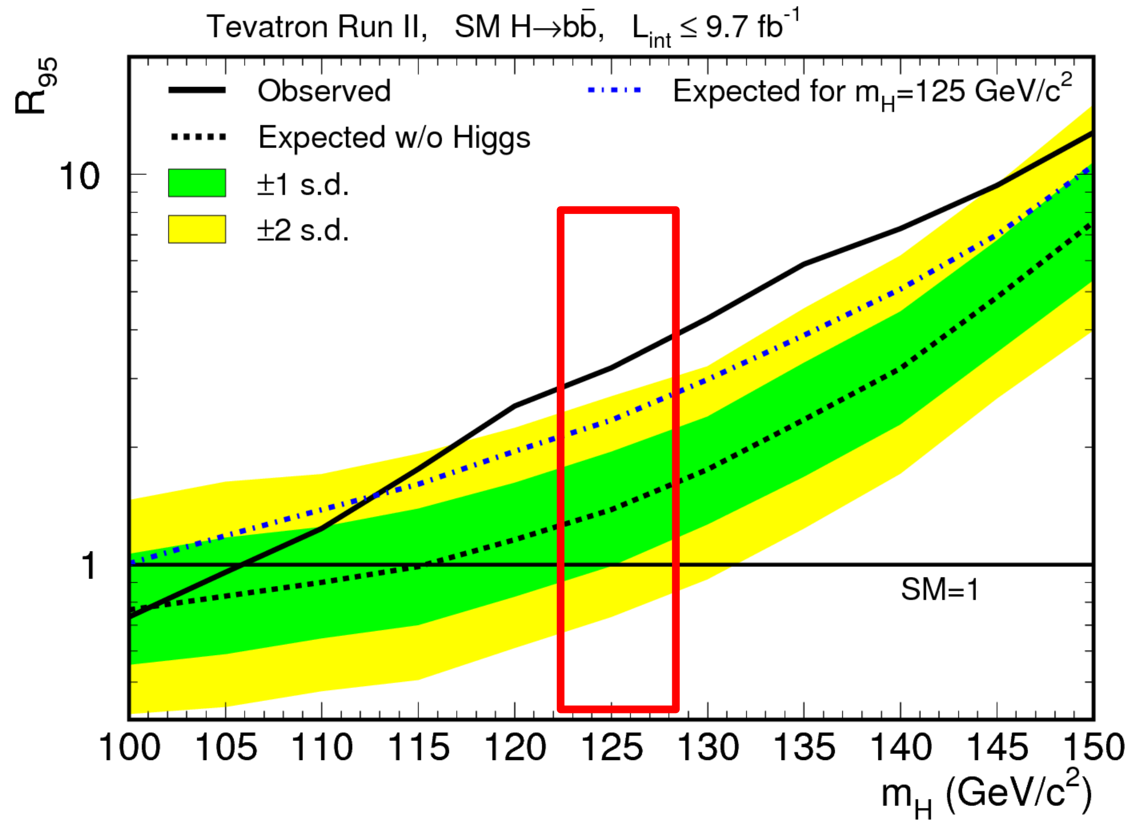
- Left: Local p-value distribution for background-only
  - Minimum local p-value: 3.0 standard deviations
  - Global p-value with LEE factor of 4: 2.5 standard deviations
- Right: bb significance





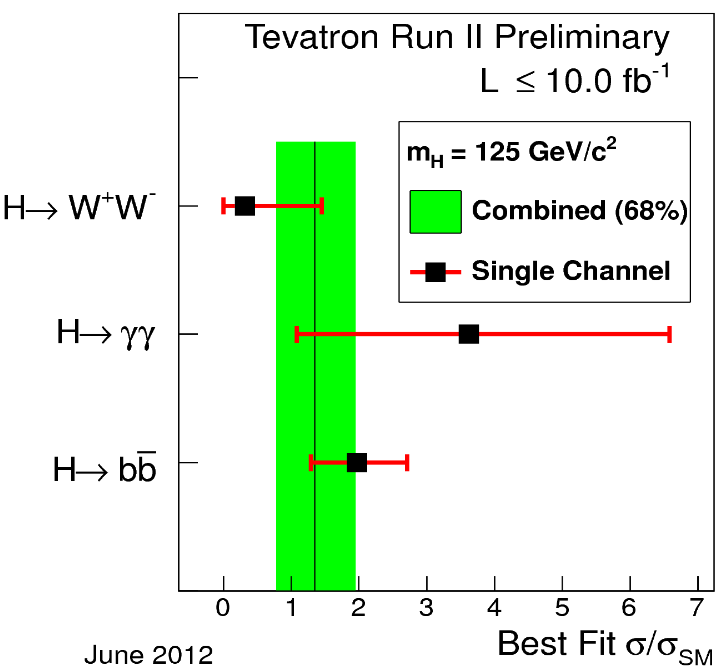
Is it signal like?

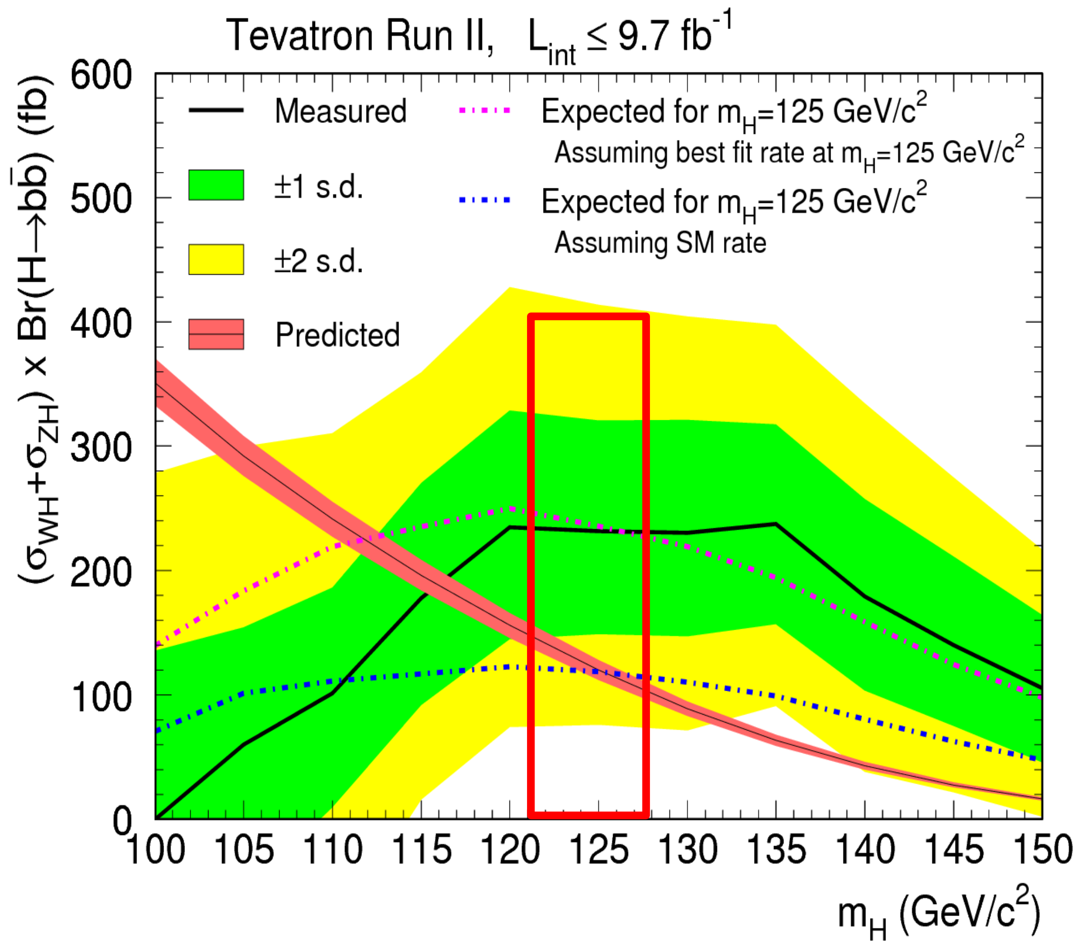
- Dotted line shows 125 GeV signal injection
- Broad excess is expected.
  - (blue dotted line)
- Not mass-sensitive
- Significance
  - Global: 3.2 Std. dev
  - Local: 2.9 Std. dev.



Is it signal like?

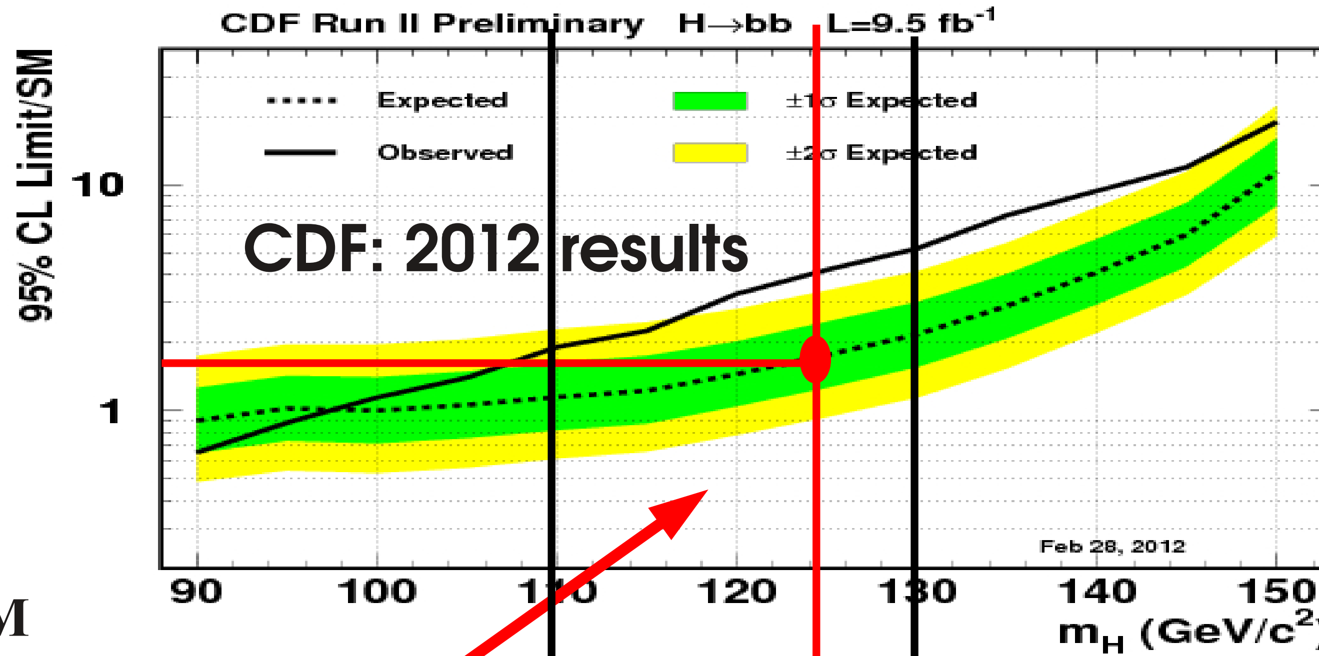
- Find signal fraction that best fits the data:
- Data look like 125 GeV SM signal injection in shape
- ~1.5 standard deviations high

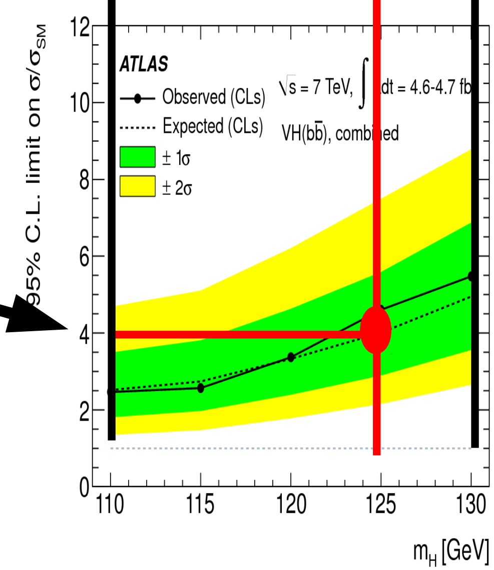




Per-channel Comparison To LHC

- **Expected Sensitivities (Feb 2012, 125 GeV):**
- **H→γγ:**
  - **ATLAS,CMS: ~1.5-2xSM**
  - **CDF, DØ: ~10-13xSM**
- **H→WW:**
  - **ATLAS,CMS: ~1-2xSM**
  - **CDF, DØ: ~3.5xSM**
- **VH, H→bb:**
  - **ATLAS (4.7/fb): ~3-4xSM**
  - **CDF, DØ (8/fb): ~2-2.5xSM**
- **2012: Tevatron's most competitive search channel is VH→Vbb!**



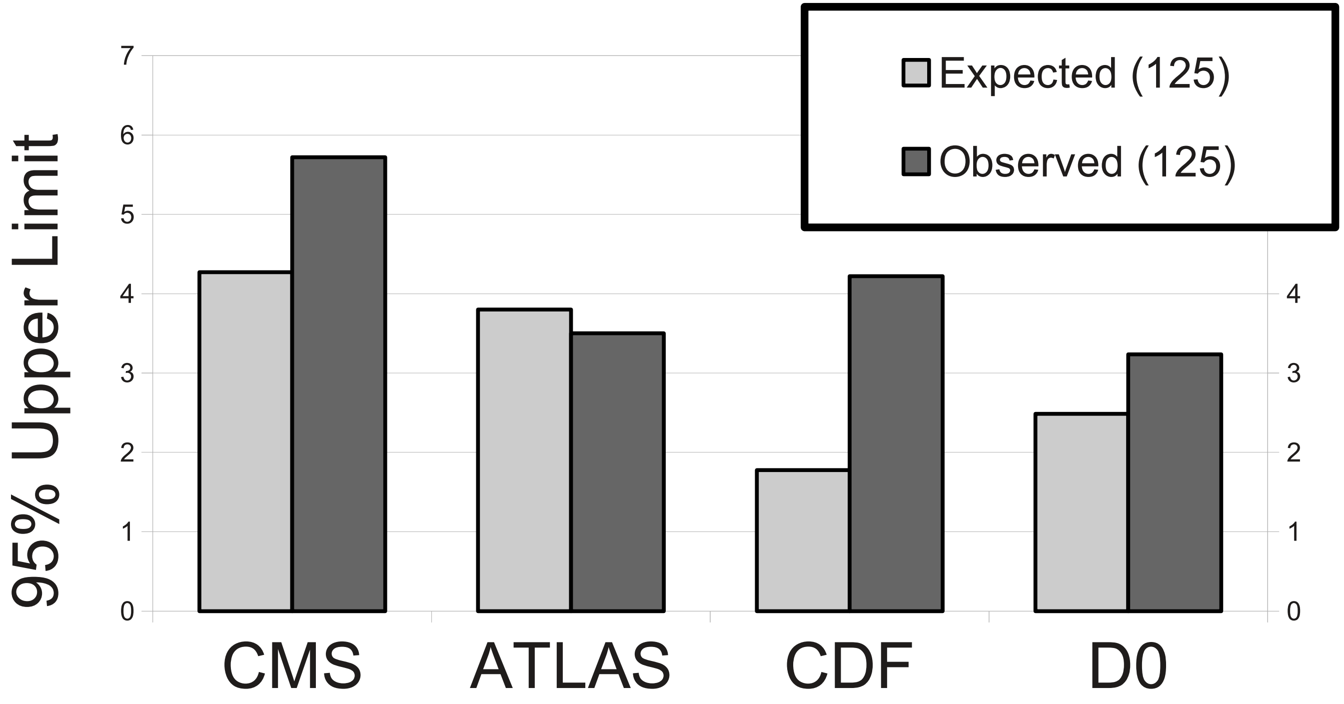


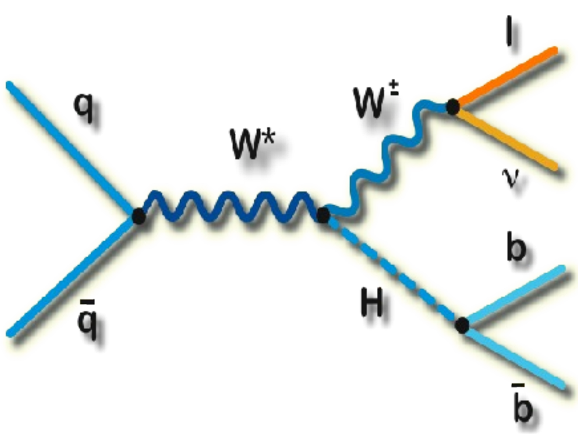
ATLAS
arXiv:1207.0210
Jul 2012

H→bb Comparison To LHC

Expected and Observed Upper 95% Limits

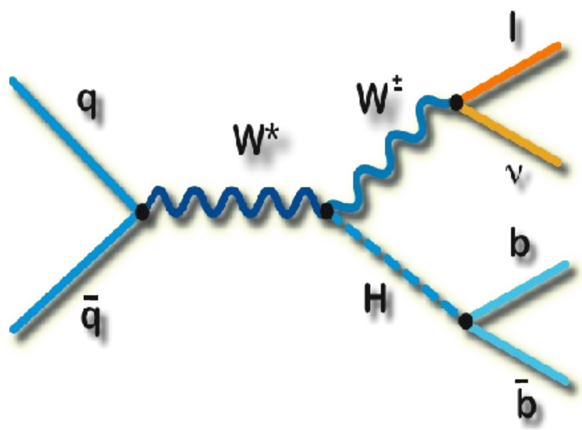
SM VH (H to bb), February 2012, Per Experiment

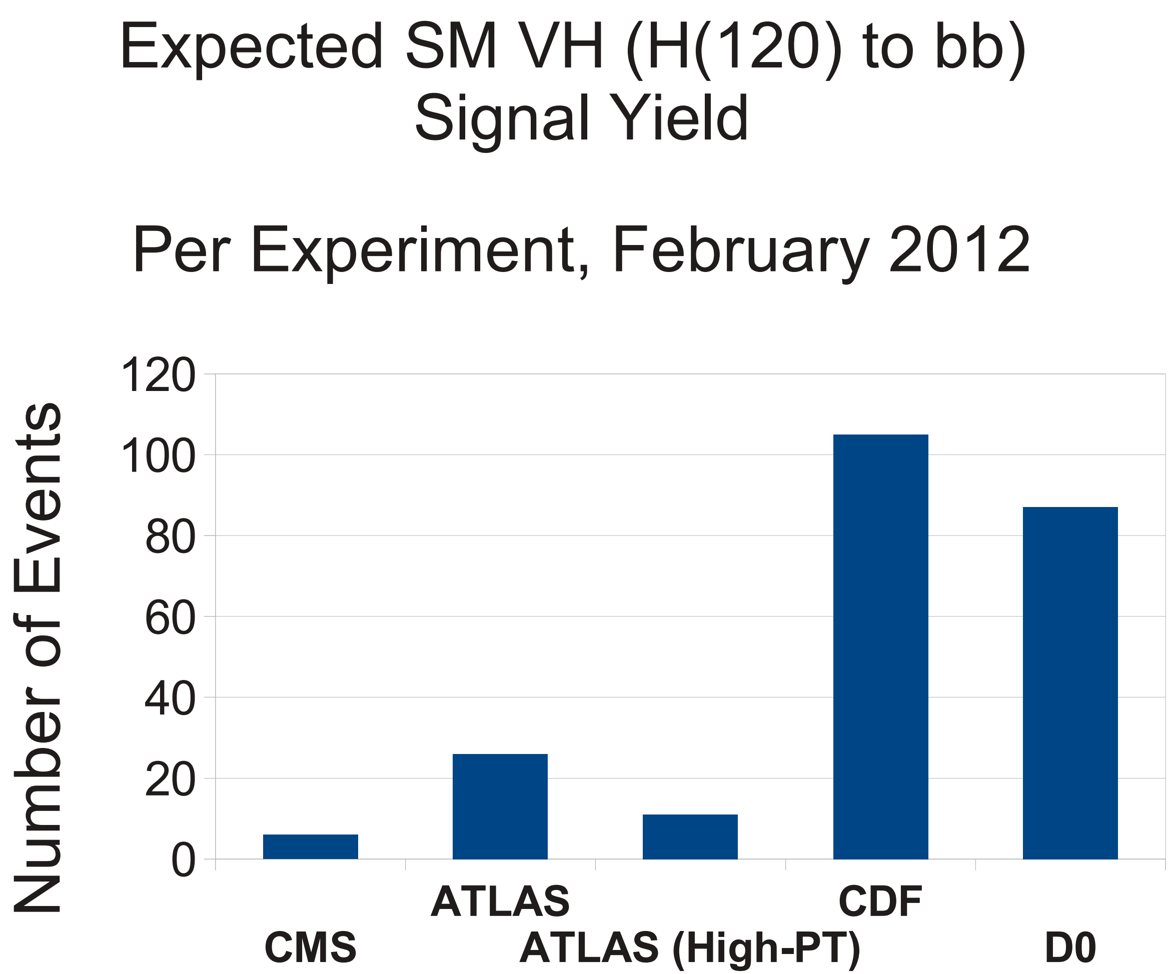




H→bb Comparison To LHC

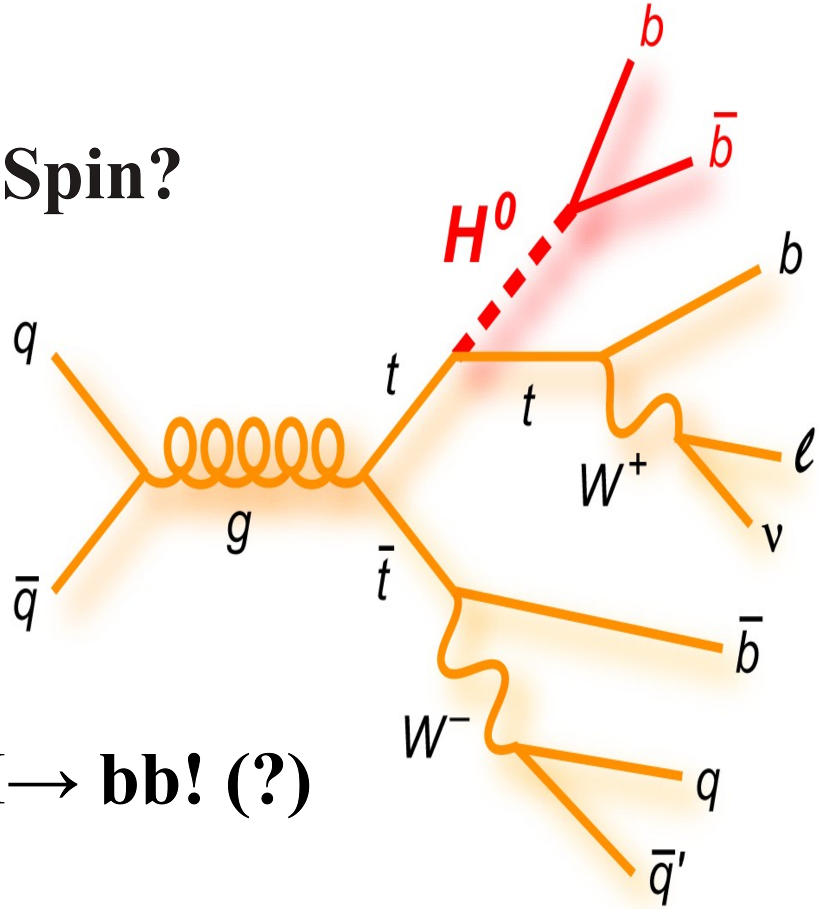
- **Tevatron Experiments:**
  ~10x Higher Expected Signal Yield





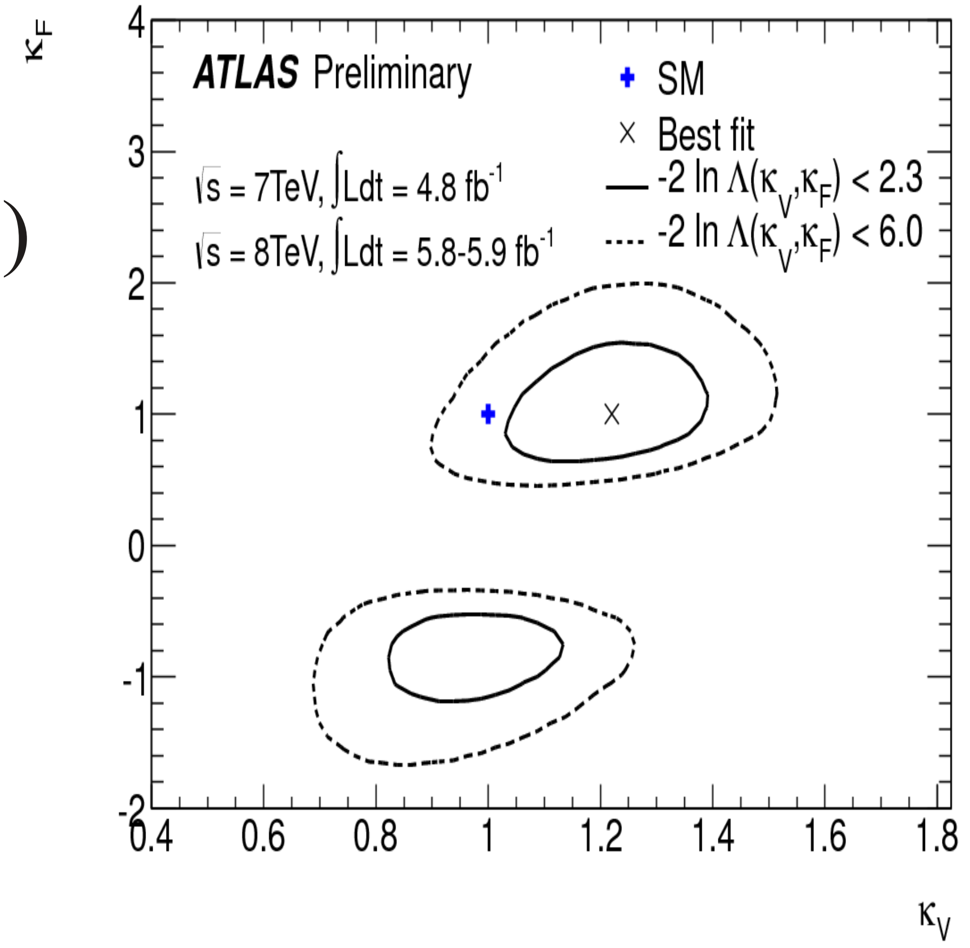
Possibilities for Winter 2013?

- **LHC mass-sensitive channels:**
  - **CMS, ATLAS: ZZ,γγ channels: Spin?**
- **LHC H→bb:**
  - **CMS: bb channels:**
    Updated for July:
    - **Currently 1.6**
      ~1.6*√10/√20 = ~0.85xSM
  - **Will soon have observation of H→ bb! (?)**
- **ttH:**
  - **CMS: Currently 4.6: 4.6*√5/√20 = ~2.3xSM**
    - **If non-SM top coupling, could have strong statement!**



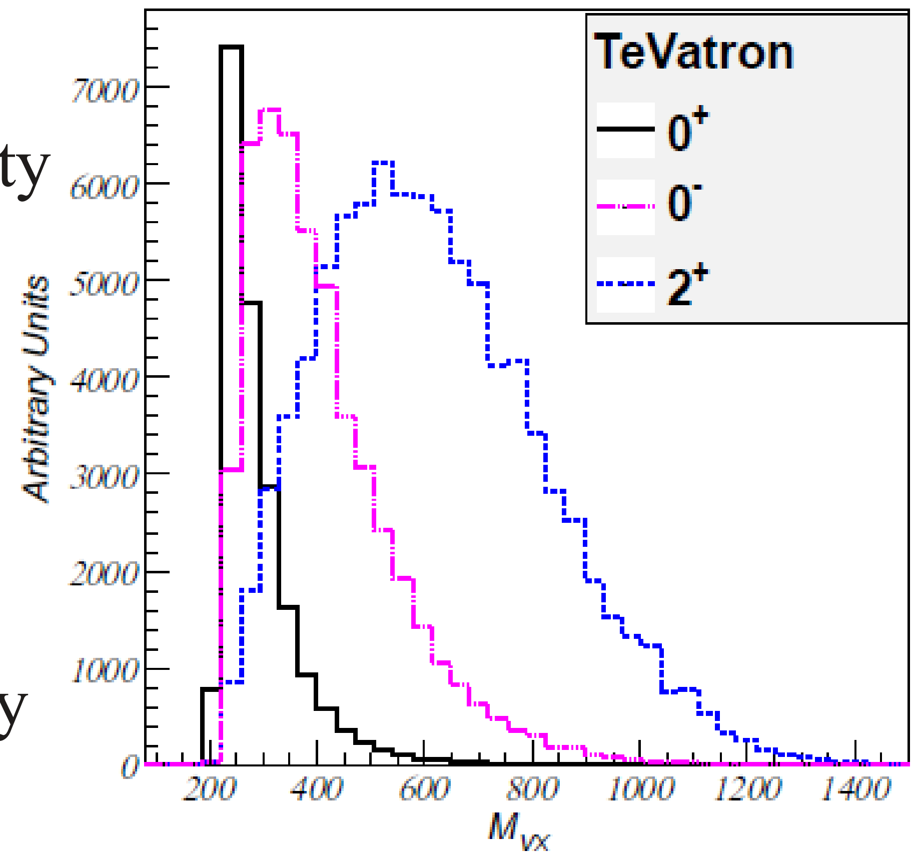
Is That All There Is?

- ATLAS and CMS have already released constraints on coupling parameters of the X(125)
  - So far SM-like
- Tevatron in progress
  - W/Z ratio
  - V/b ratio
- Testing with WW/WZ



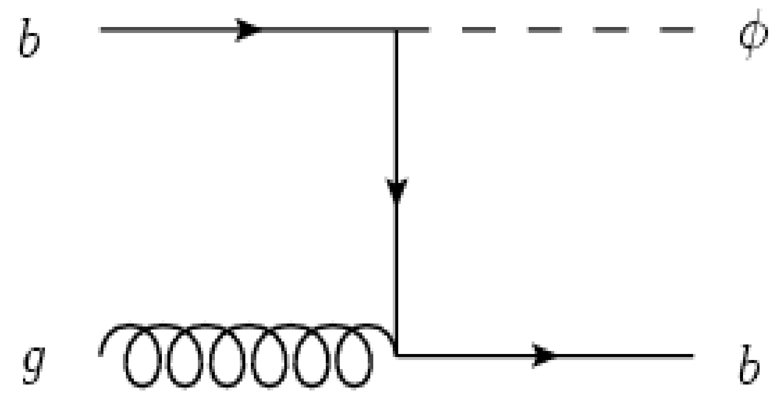
Is That All There Is?

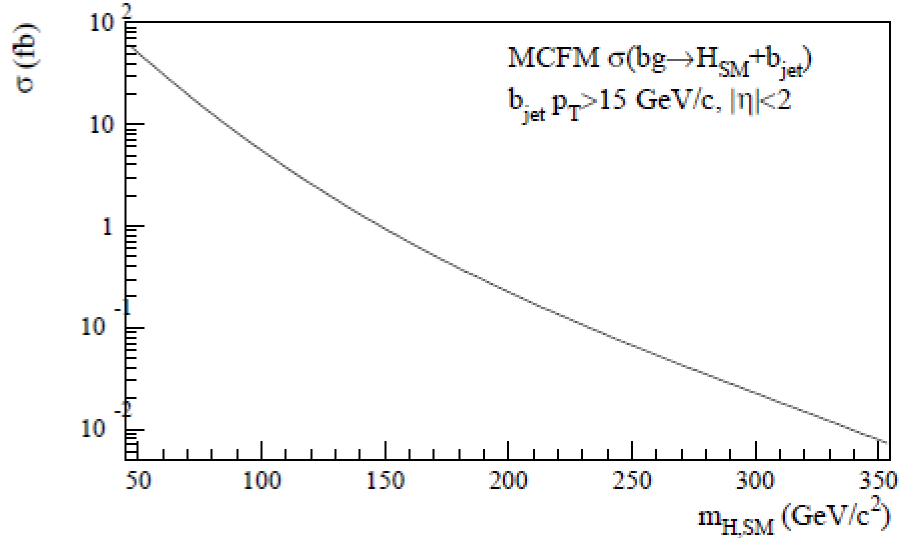
- Interesting paper: arXiv:1208.6002v1 J.Ellis, D.S.Hwang, V.Sanz, and T.You
- M(VH) can differentiate spin, parity
- Caveat: “We have not analyzed further the backgrounds in the experiments,”
  - Tevatron background are non-negligible in VH processes
- We are Investigating our sensitivity



CDF bh→bbb Analysis

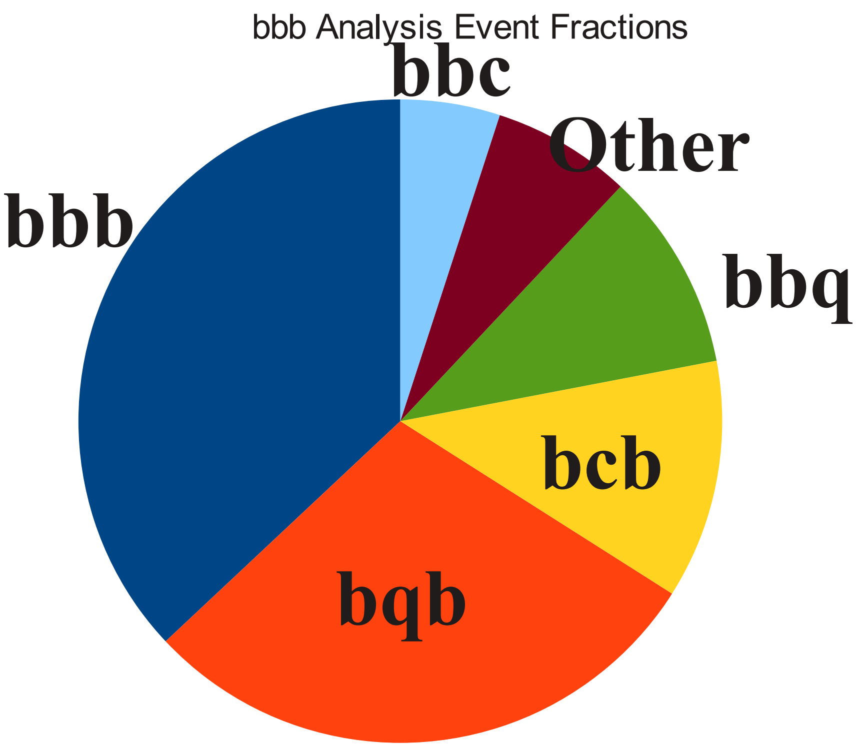
- What about models with H-like particles?
  - Technicolor? (Underway)
  - MSSM?
- Recent combination of CDF and D0 searches for bh→bbb:
  - Final state (CDF)
    - >=3jets
    - >=3 b-tags
- Analysis relies on b-jet trigger





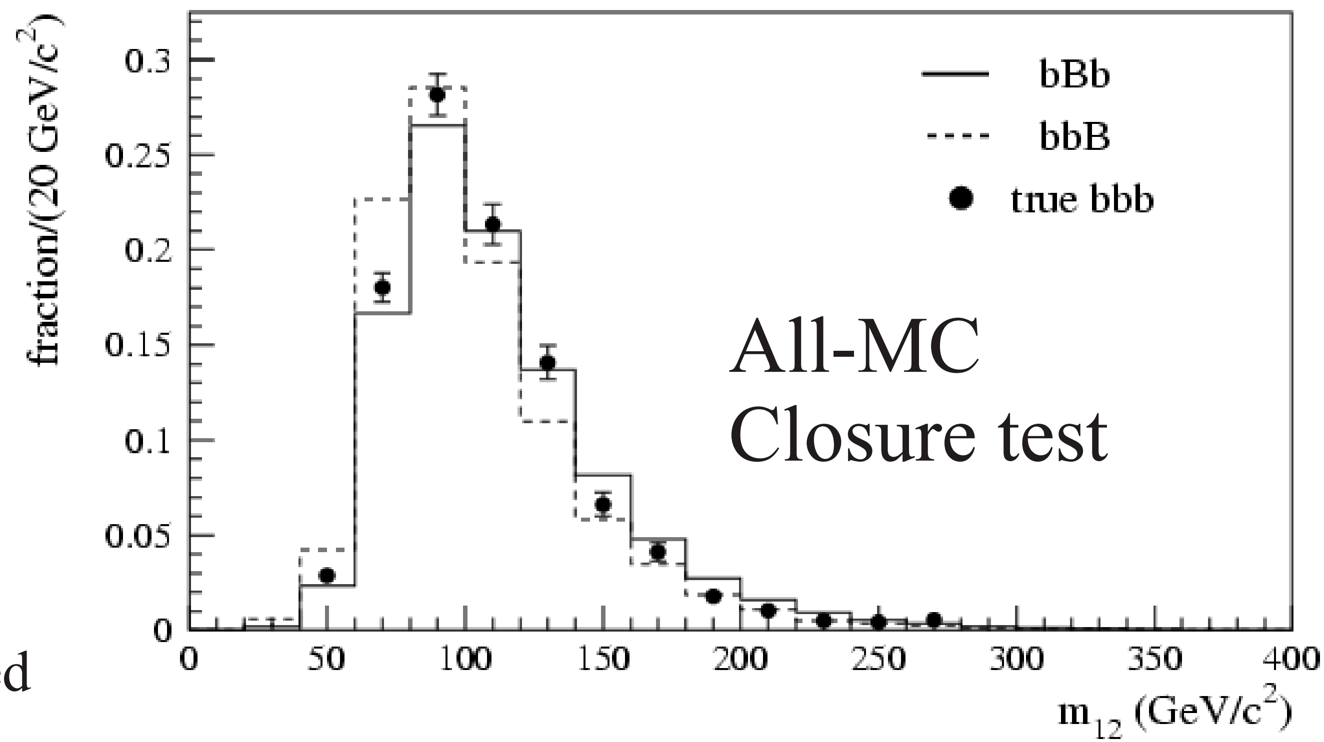
CDF bh→bbb Analysis

- Background is ~100% QCD
  - Don't trust MC
  - Use Data-driven background model
    - Templates from 2-tag data
    - Assume flavor and tag rate of third tag
  - Don't trust flavor-fractions
    - Fit to data



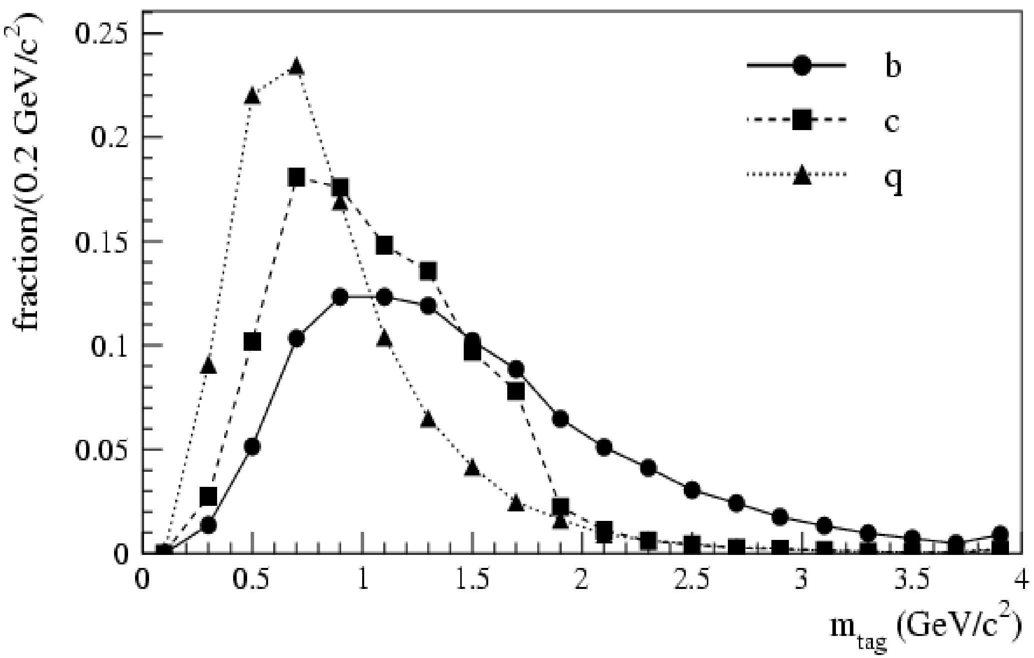
CDF bh→bbb Analysis

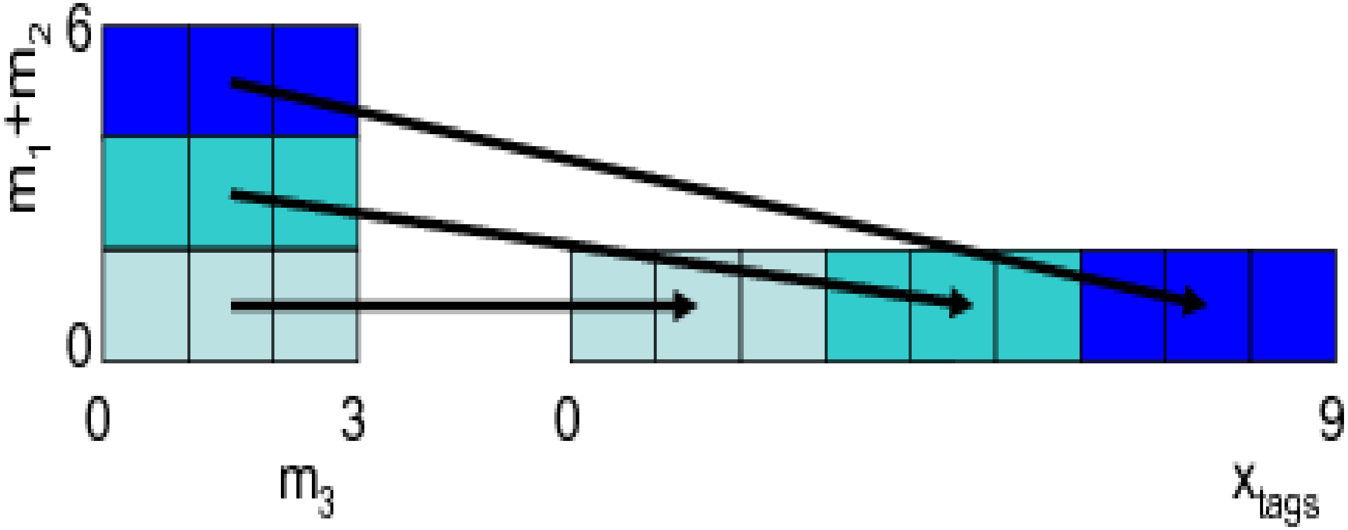
- How to construct templates
  - Take data events
    - >=3 jets
    - ==2 tags
    - Order in ET
  - Now weight untagged jet
    - bbB or bBb?
    - Which jet was originally untagged
- Note that the bbb Mj1j2 spectrum is in-between bbB and bBb



CDF bh→bbb Analysis

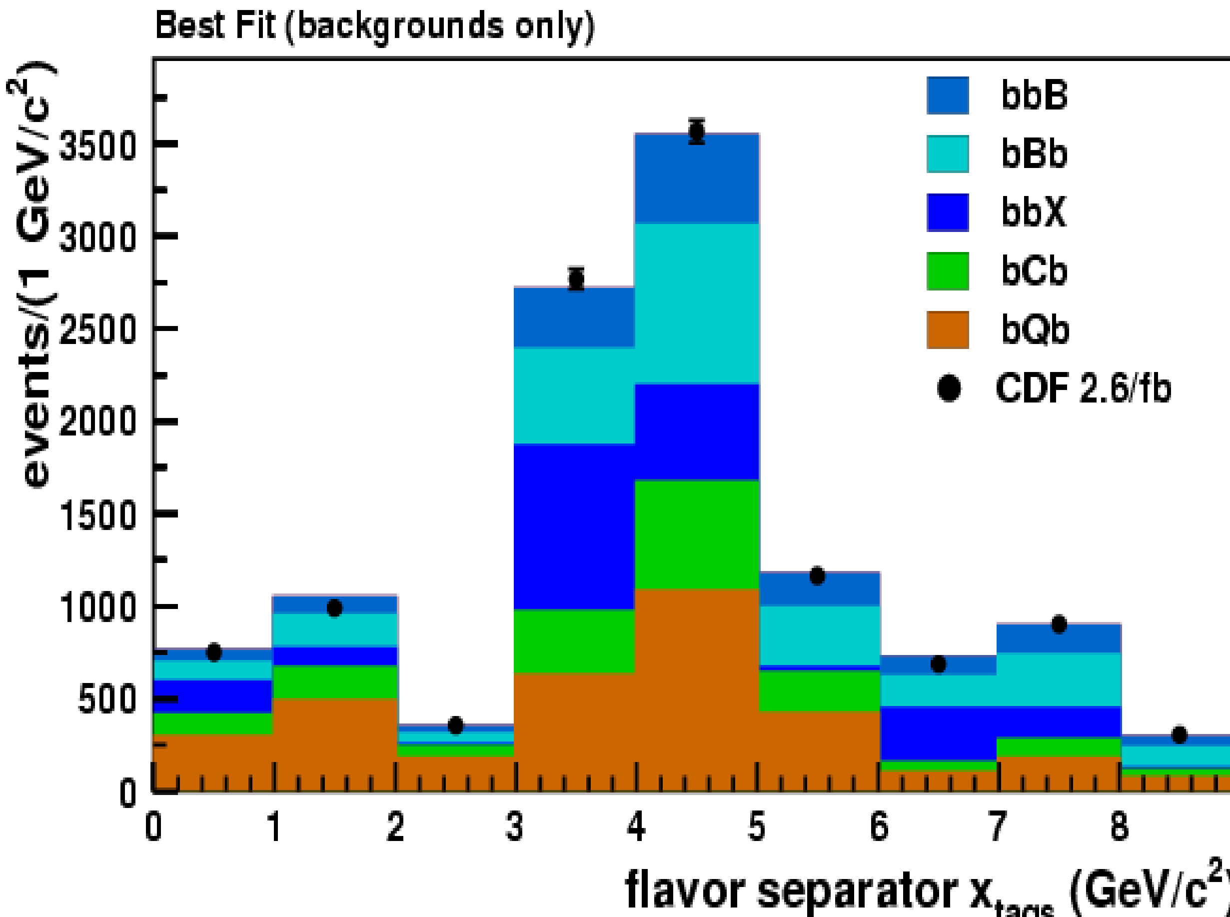
- Now, fit background templates in 3 dimensions
  - Mj1j2 (signal sensitivity)
  - m1+m2 (flavor sensitivity)
  - m3 (flavor sensitivity)

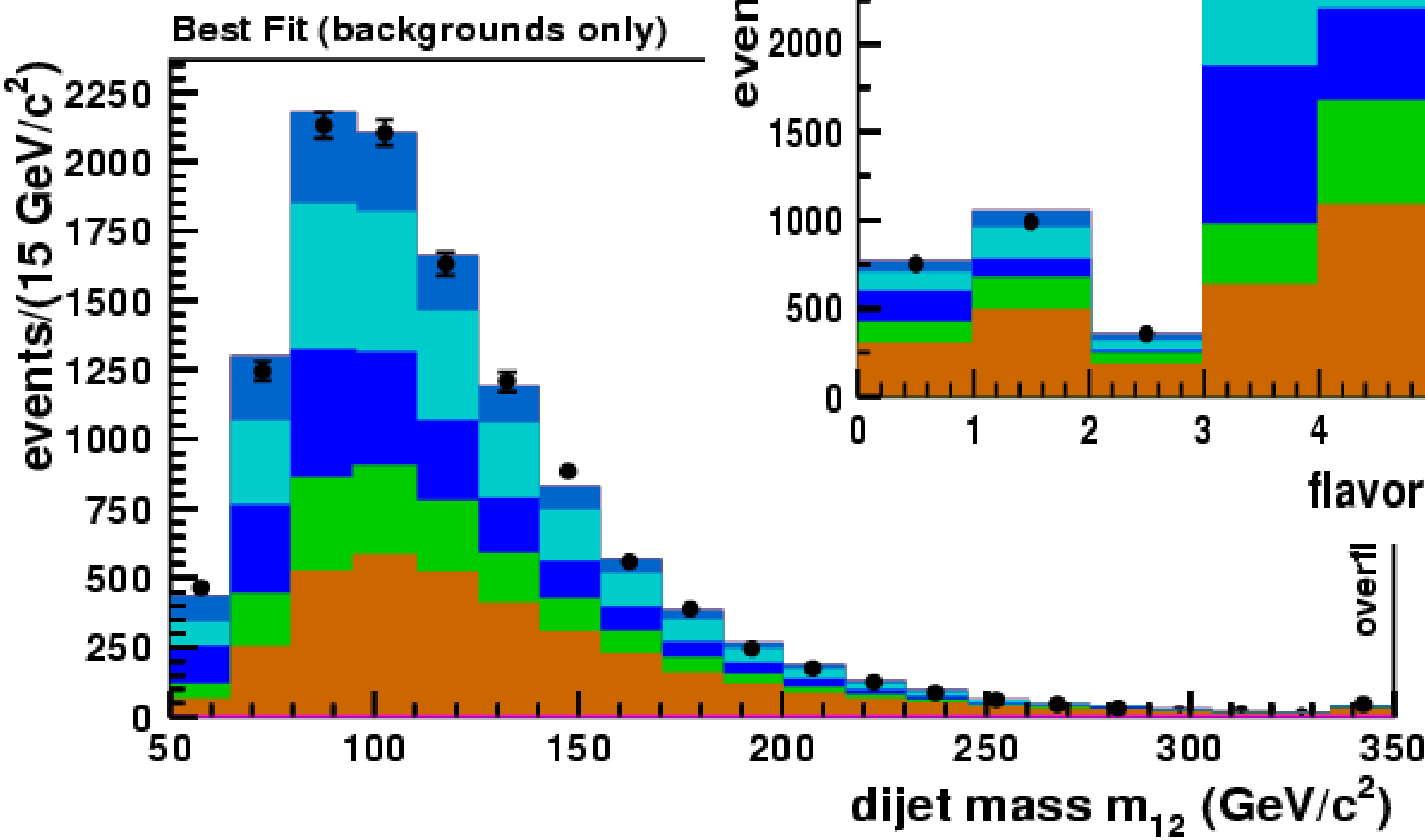




CDF bh→bbb Analysis

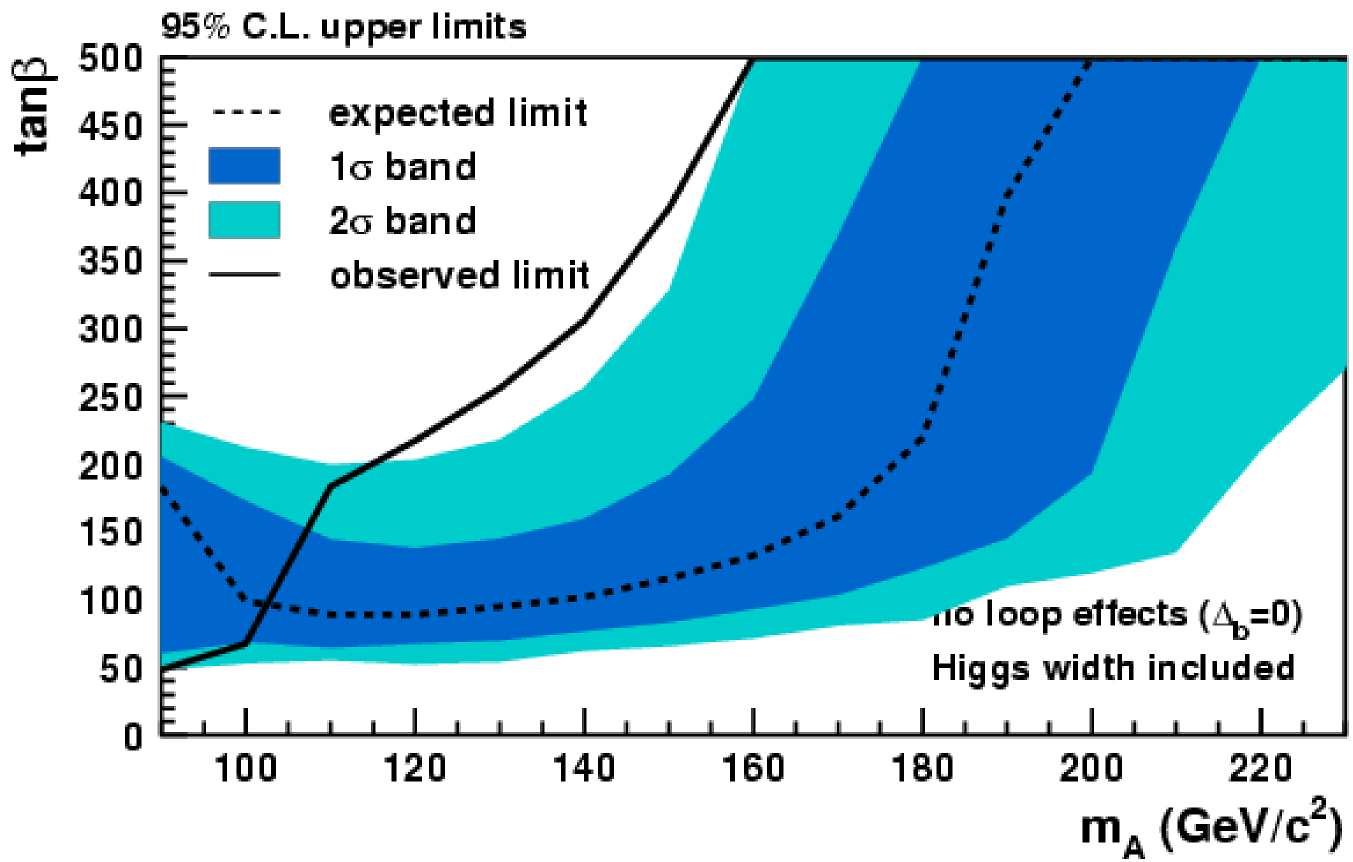
- Fit Results

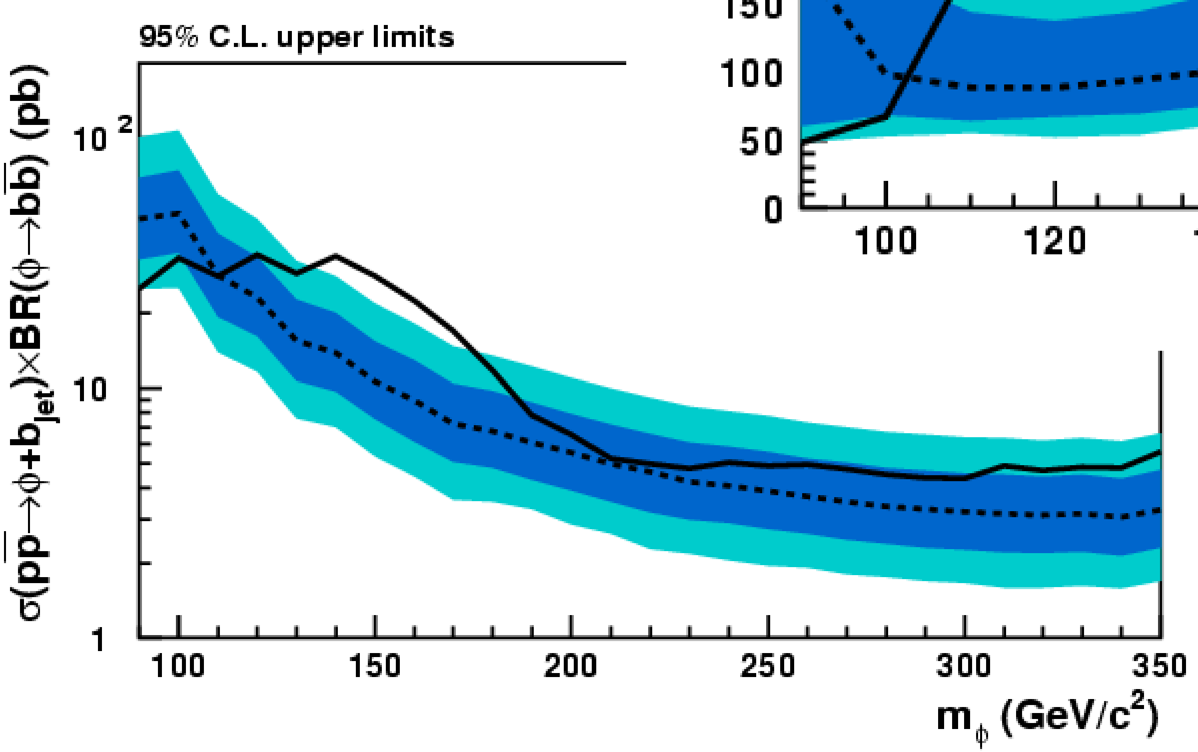




CDF bh→bbb Analysis

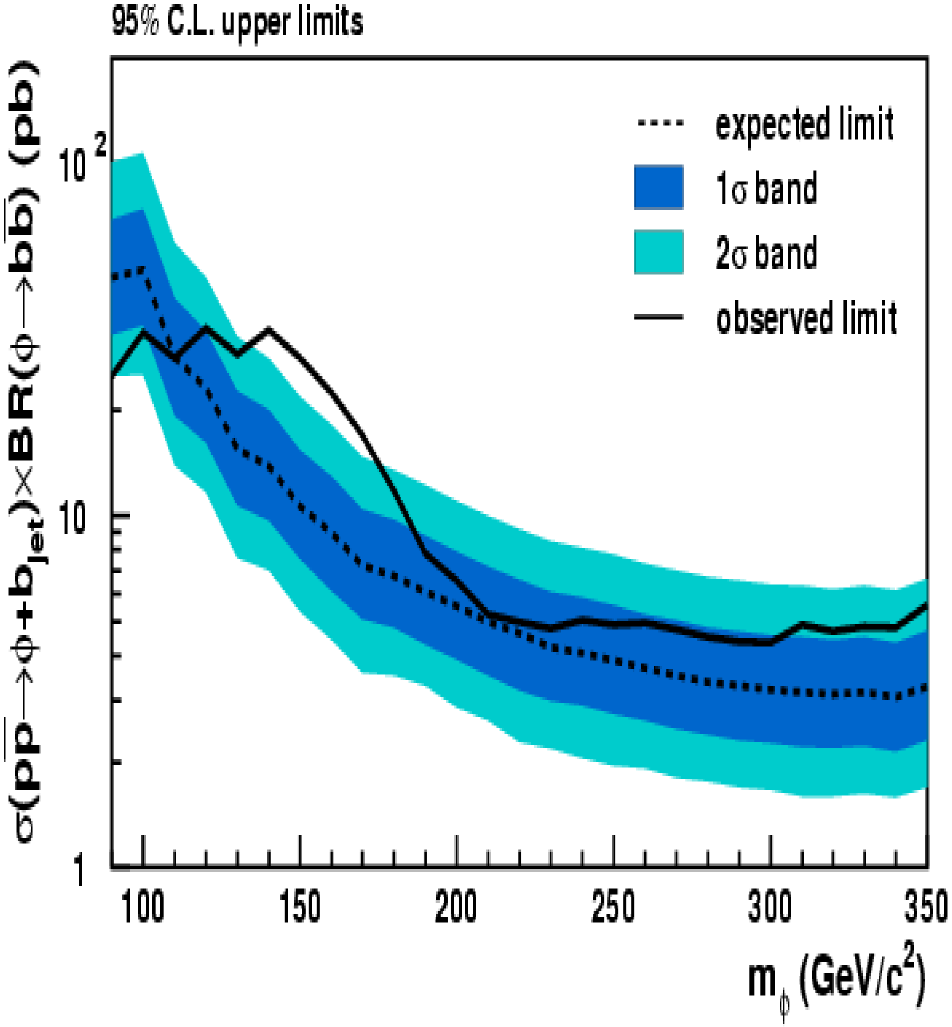
- Search Results
  - 2.8 sigma local significance at 150
  - 1.9 global

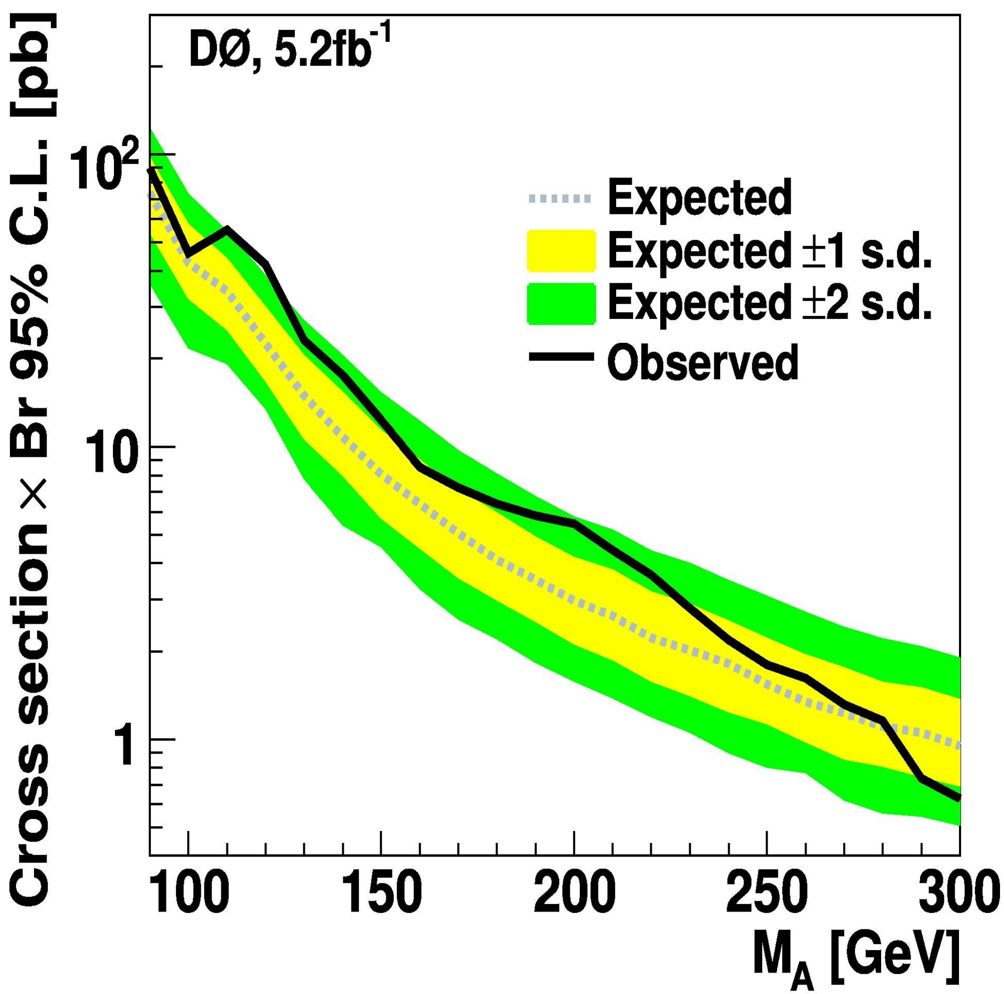




CDF bh→bbb Analysis

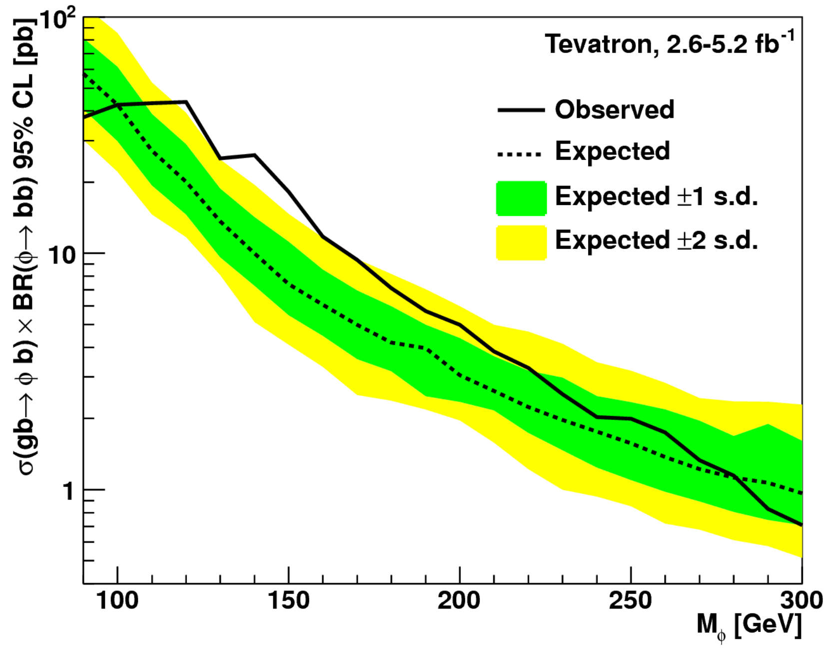
- Combine with D0
- Similar sensitivities, different excesses

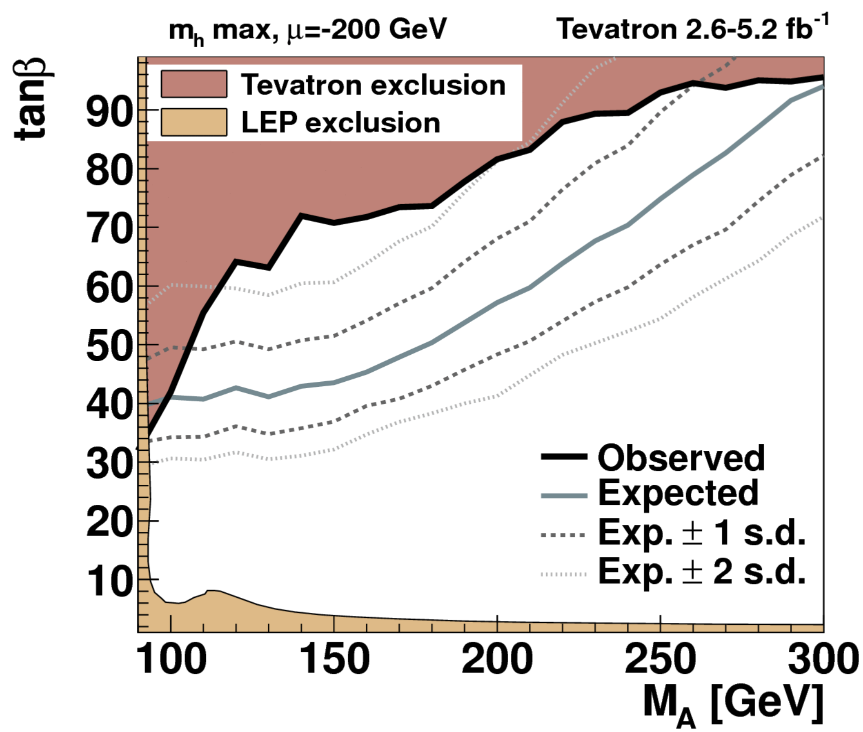




Is That All There Is?

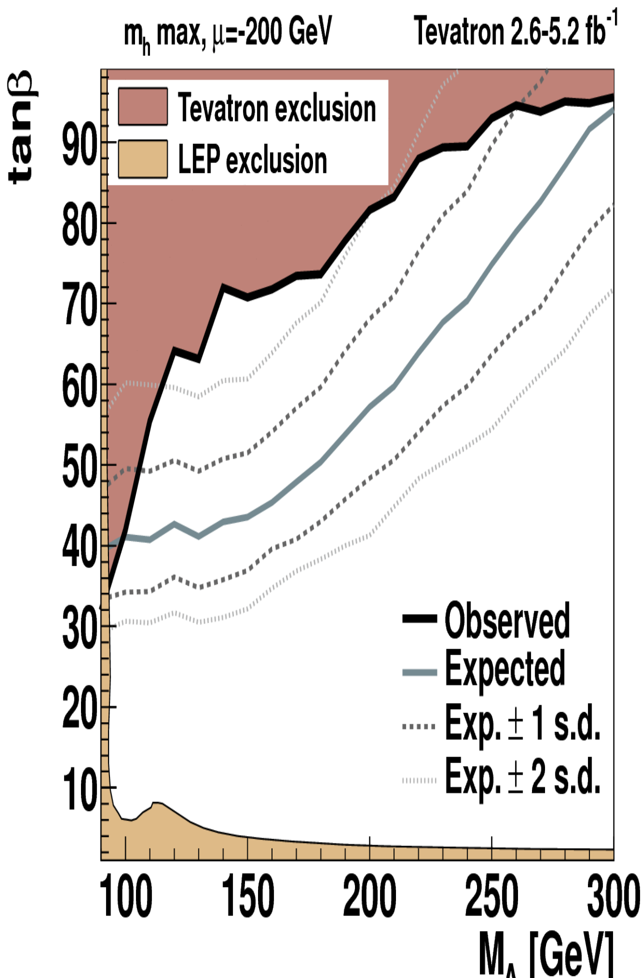
- Combined results
  - Two excesses sum to single, softer, broader excess

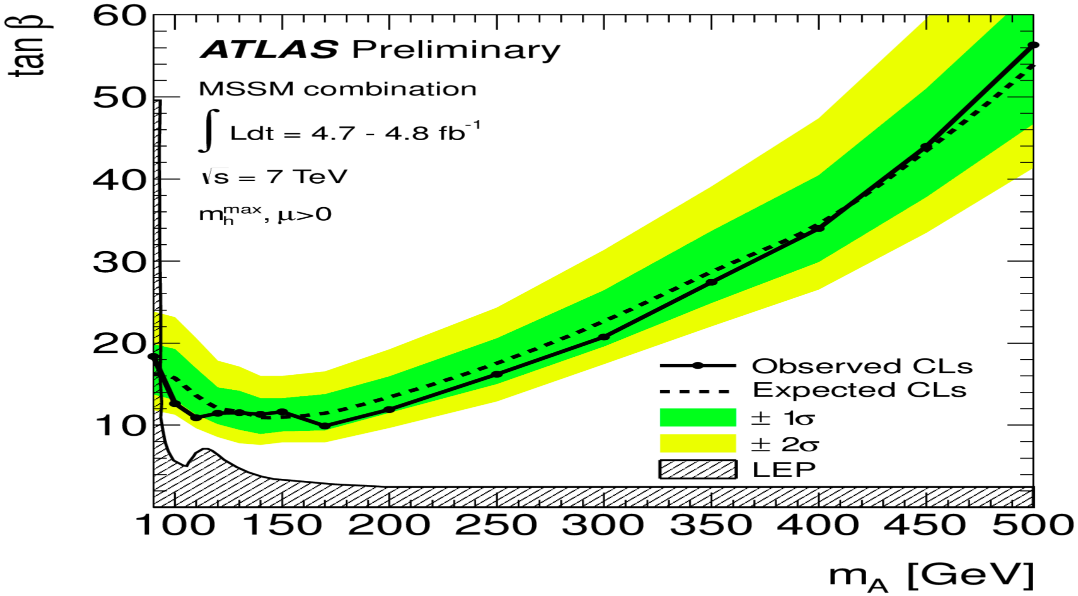




Is That All There Is?

- Comparing to the ATLAS results, mh max scenario
  - NB, ATLAS, CMS results use h→μμ/ττ, not bb!





Recent Publications

- **CDF METbb: arXiv:1207.1711, Phys. Rev. Lett. 109, 111805 (2012)**
- **CDF WH: arXiv:1207.1703, Phys. Rev. Lett. 109, 111804 (2012)**
- **CDF ZH: arXiv:1207.1704, Phys. Rev. Lett. 109, 111803 (2012)**
- **CDF H→bb: arXiv:1207.1707, Phys. Rev. Lett. 109, 111802 (2012)**
- **TeV H→bb: arXiv:1207.6436, Phys. Rev. Lett. 109, 071804 (2012)**
- **CDF ttH: arXiv:1208.2662 (Accepted to PRL)**
- **Tevatron bbb: arXiv:1207.2757 (Accepted to PRL)**
- **CDF bbb: arXiv:1106.4782, Phys. Rev. D 85 032005 (2012)**
- **TeV bbb: arXiv:1207.2757 (Accepted to PRL)**

More possibilities for 2013

- CDF still has collaborators preparing results
  - Most people sharing time on other experiments
  - Updating METbb analysis to new tagger
    - Different BG model, so WH/ZH tools aren't turnkey usable. (+2-3% sensitivity)
  - New Higgs-related results focus on states where the Tevatron can compete
    - Low-mass decays
    - Not sensitive to pile-up

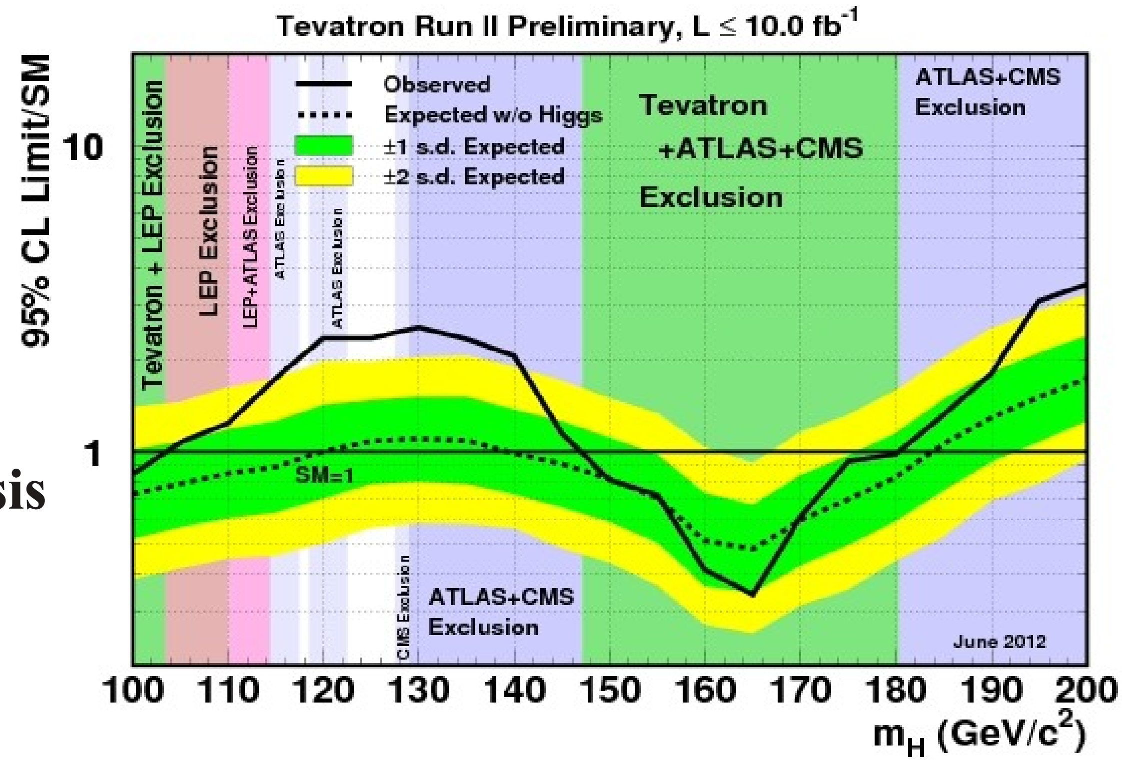
Conclusions

- **For additional details see**
  - Tevatron: http://tevnphwg.fnal.gov/results/SM_Higgs_Summer_12/
  - CDF: http://www-cdf.fnal.gov/physics/new/hdg/Results.html
  - DØ: http://www-d0.fnal.gov/Run2Physics/WWW/results/higgs.html

- Thanks to everyone at CDF and DØ who contributed to this update!
- Bigger thanks to everyone who designed, built, or operated CDF or DØ!
- FNAL Computing Division: Thanks for all the computing power and software!
- FNAL Beams Division: Thanks for all the collisions!
- Photographs of Fermilab and its wildlife were taken by Reidar Hahn, FNAL VMS

Conclusions

- CDF & DØ SM Higgs searches have been updated with the complete RunII dataset
  - Expected sensitivity <1.10xSM over interesting range
  - Dominated by associated production and WW channels

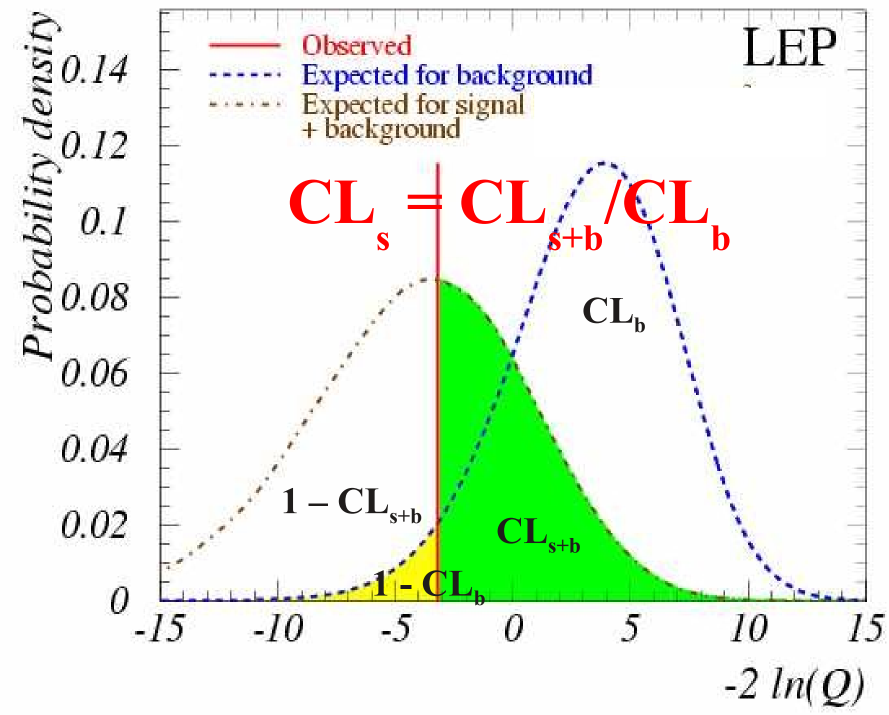


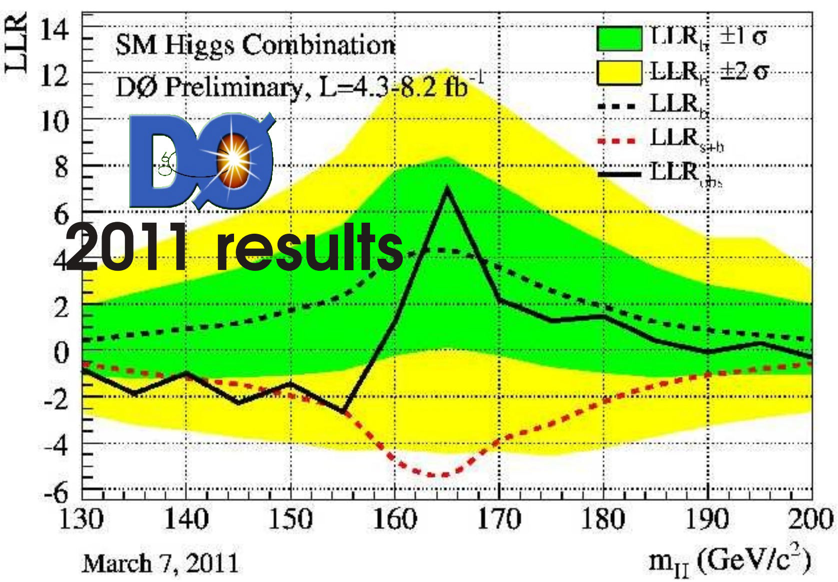
- The data are
  - incompatible with background-only hypothesis,
  - compatible with signal hypothesis
  - Agreement among six channels, 2 experiments
  - global p-value of 2.5 s.d.
  - H→bb only: global 3.1 s.d.
  - Evidence for H→bb!

Backup Slides

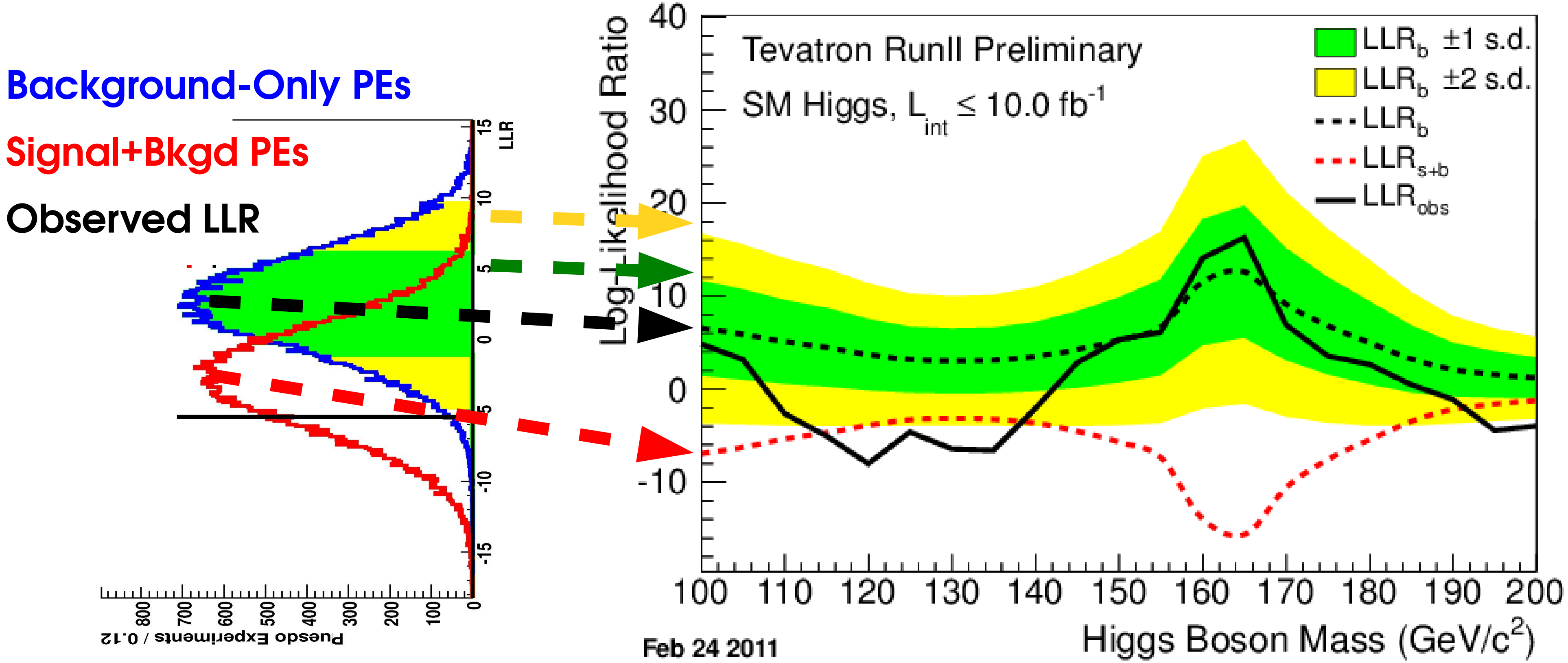
Modified Frequentist Searches (DØ)

- **Define test statistic:**
  - **Log Likelihood Ratio: L(s+b)/L(b)**
  - **Throw pseudoexperiments generated under background or s+b hypotheses**
  - **Separation between LLR distributions is discovery power**
  - **Compute CL(s) = CL(s+b)/CL(b)**
  - **Vary assumed signal cross section until CL(s)=5%**
    - **Signal cross section meeting this criteria is the upper limit**
- **CDF and DØ set limits both ways: Frequentist and Bayesian**
  - **Two methods agree to ~1%**





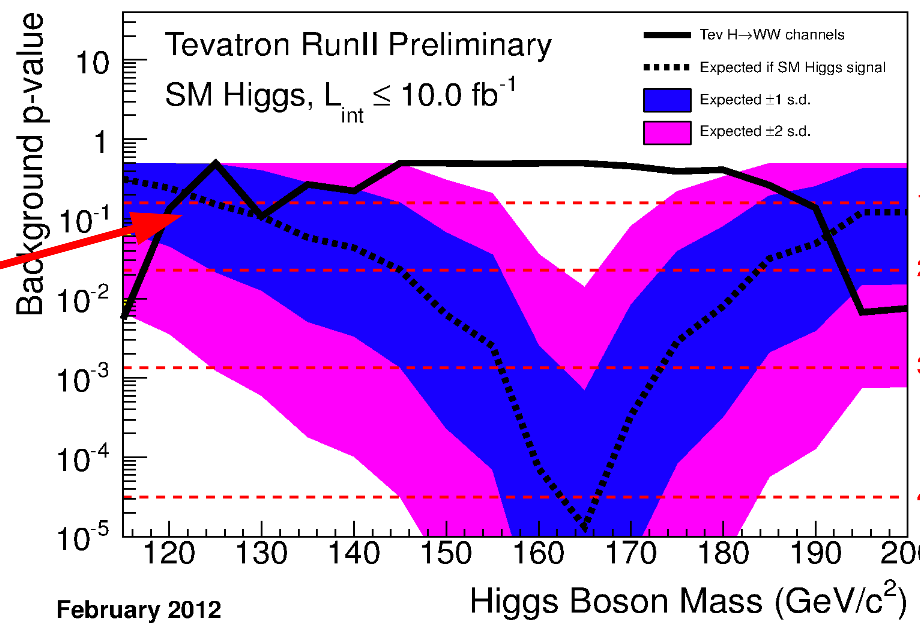
Understanding Sensitivity

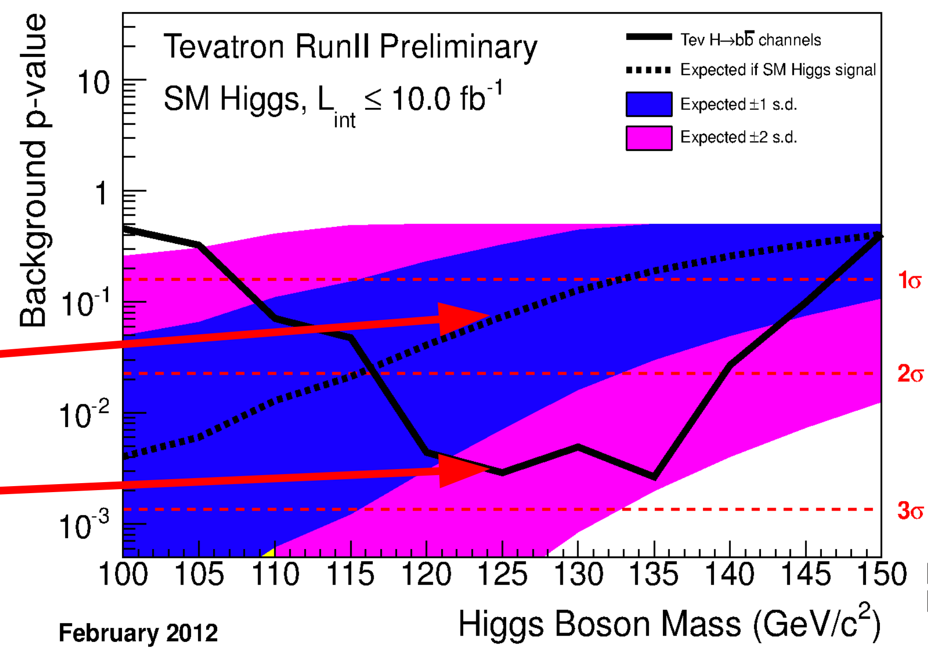


- Log-likelihood ratio at different masses shows what signal-like deviations across the mass range would indicate, relative to signal separation power

Quantifying The Excess: H→bb and H→WW

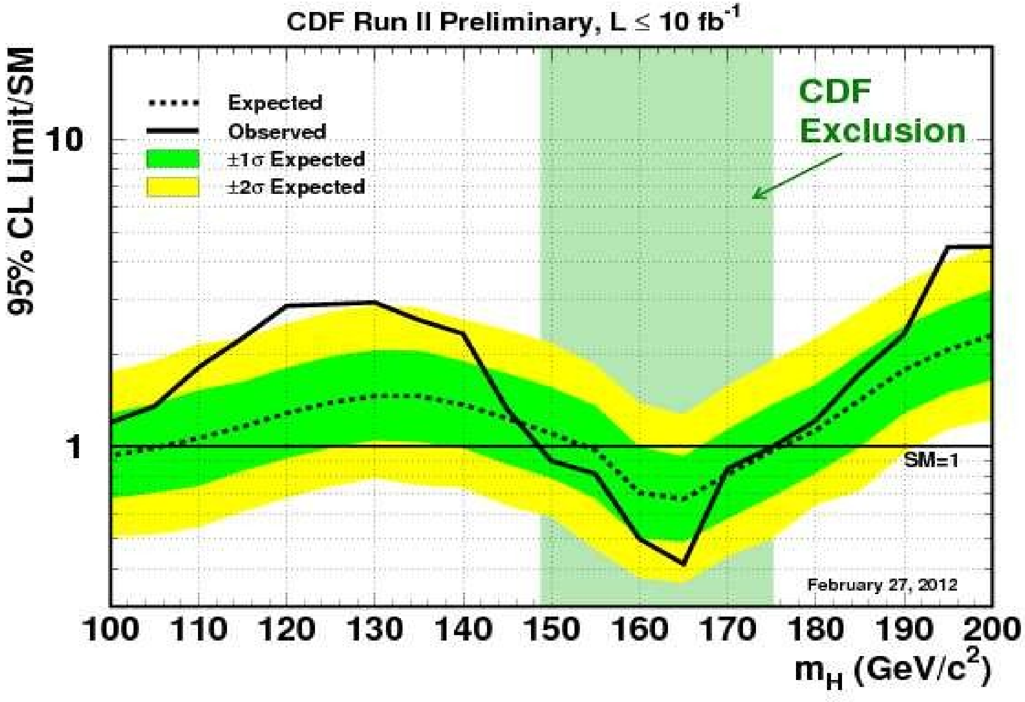
- Local p-value distribution for background-only expectation.
- WW: Don't expect a significant excess
- H→bb
  - Min local p-value: 2.8 standard deviations
  - Global p-value with LEE factor of 2: 2.6 standard deviations
  - At 125: Like SM Higgs with an additional ~1.5-sigma upward fluctuation

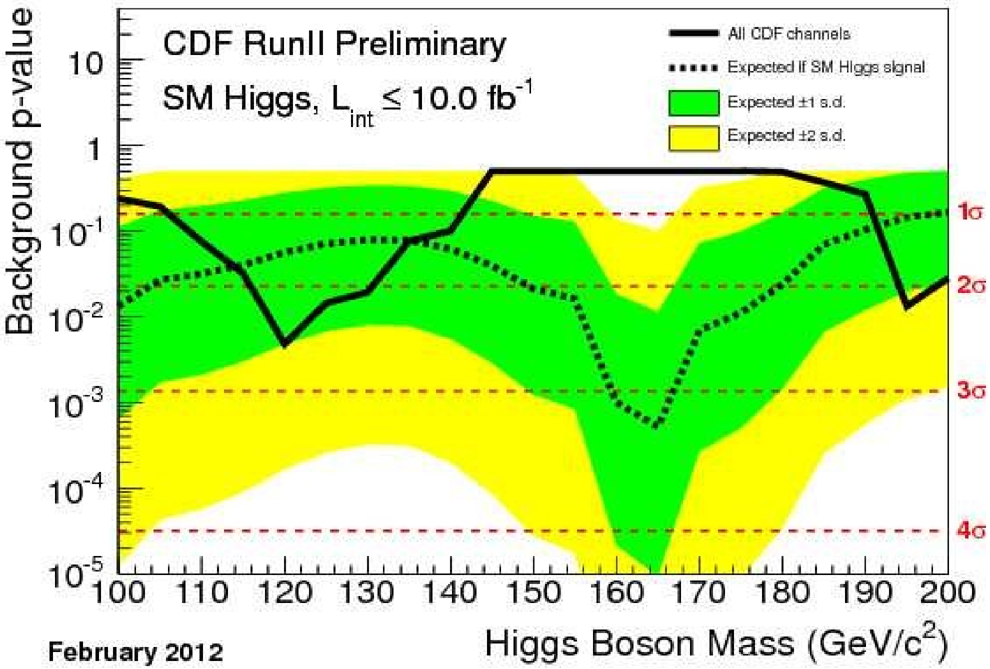




CDF Combination

- Exclude from 147 to 175 GeV
- Two excesses:
  - one from associated production modes
  - one at ~200 GeV.
- At 120 GeV, global p-value is 2.1-sigma

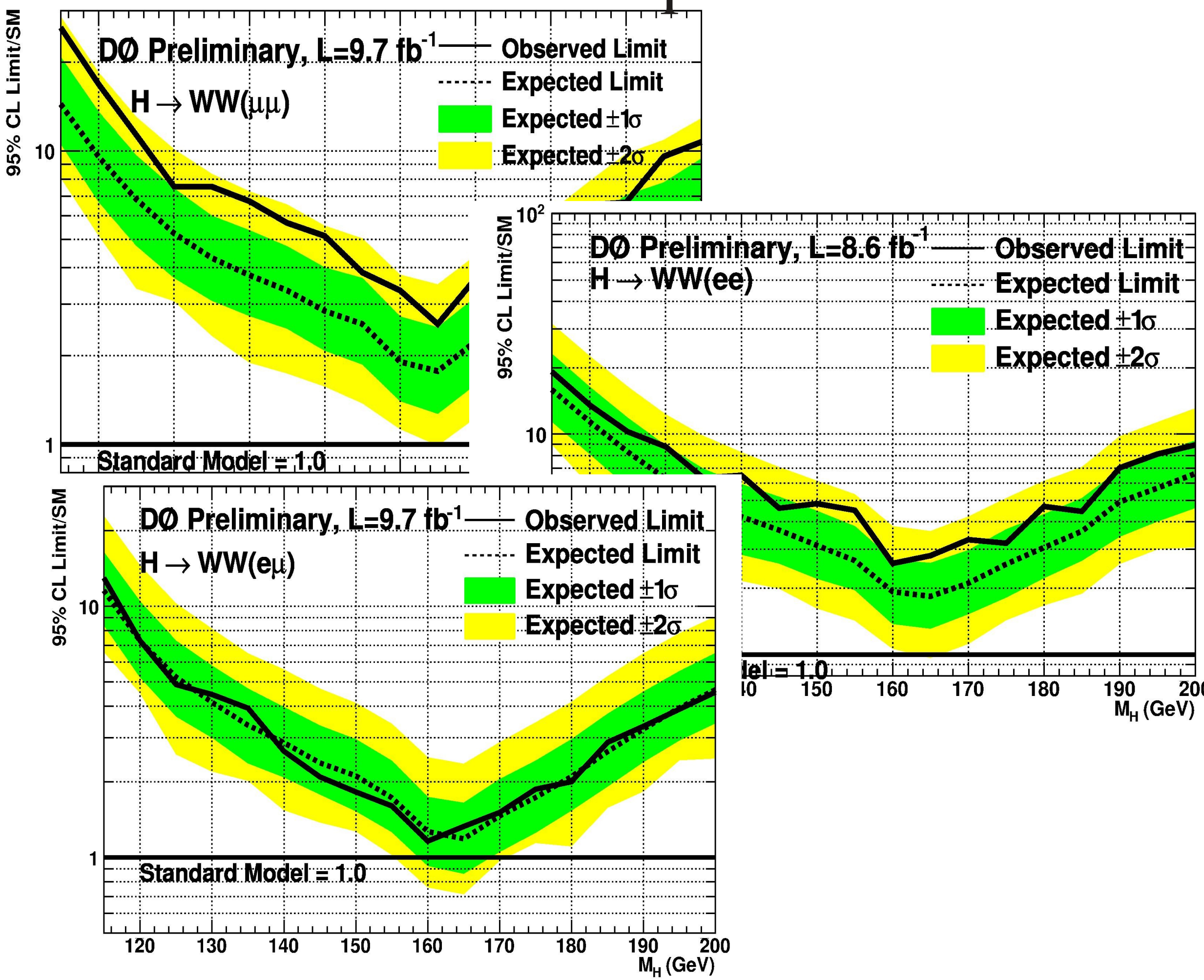




High-Mass Combined Searches

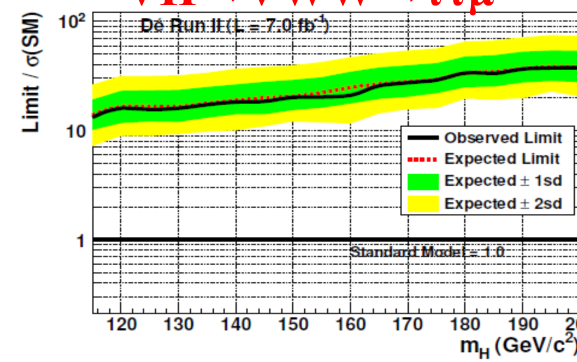
DØ: 3-lepton * 3-jet sub-channels

- Plus 3 new VH trilepton!

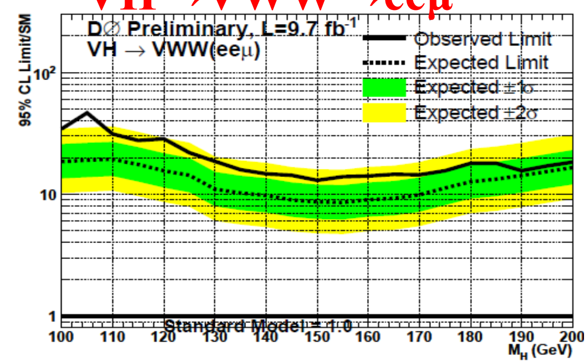


New analyses!

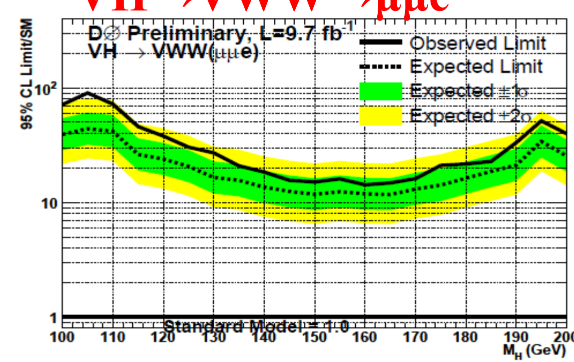
VH→VWW→ττμ



VH→VWW→eeμ

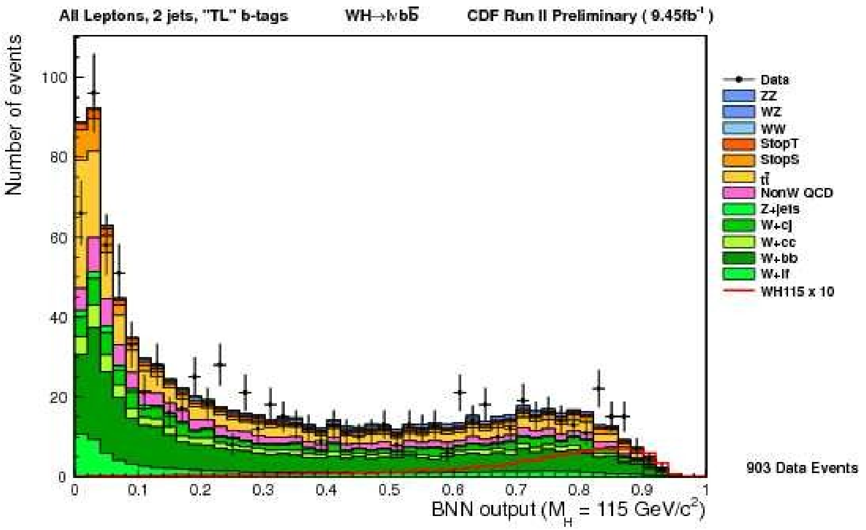


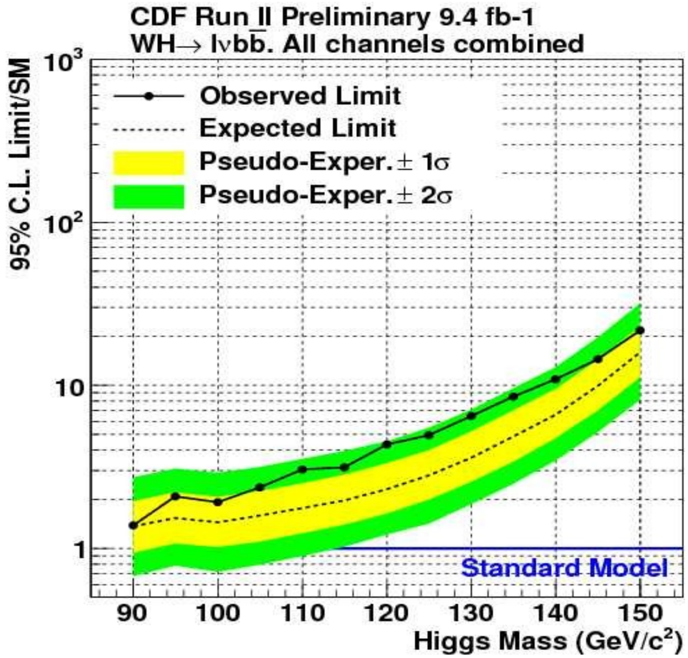
VH→VWW→μμe



WH Results

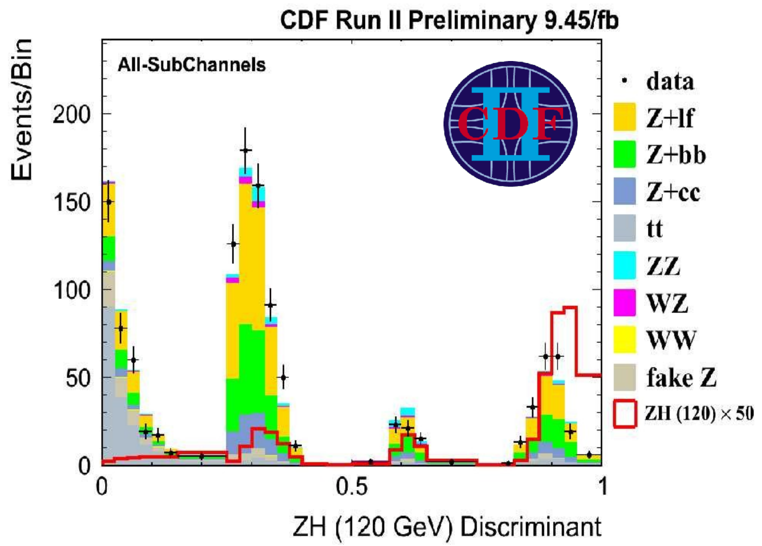
- WH:
- Major background
  - W+bb, ditop, instrumental nonW.
- Added data + improved b-tagging + new triggers
- update of 3jet bin
- Best s/b: ~1:5
- 2012: 22.7→40.2 expected signal events!!!
- 1-2012/2011=~30% stronger expected limits than summer 2011

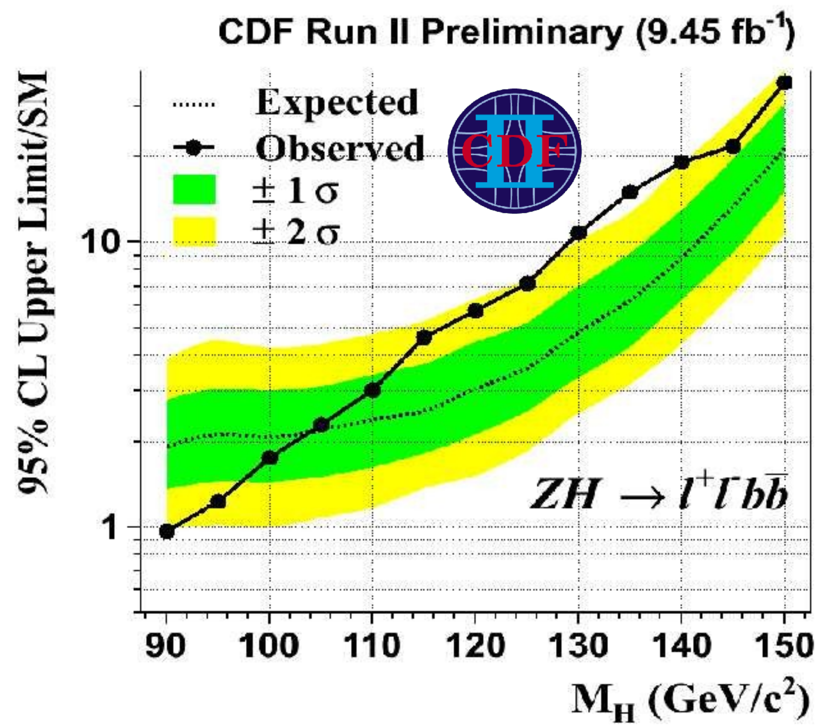




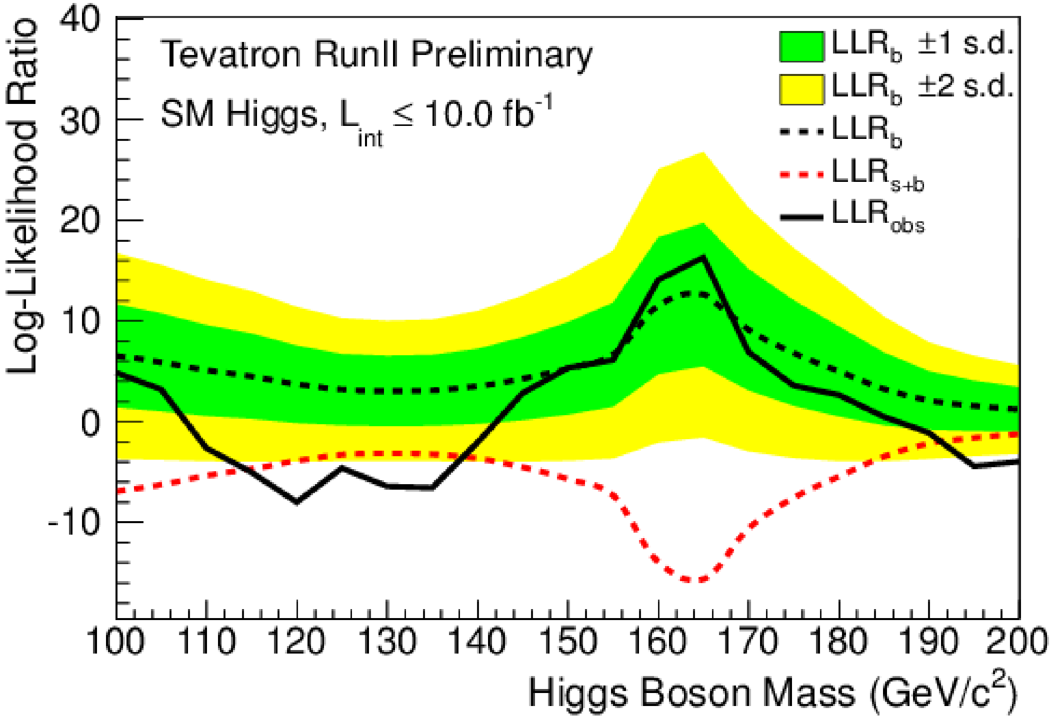
ZH Results

- Major backgrounds:
  - Z+bb, ditop
- Improvements
  - Added data + improved btagging
    + better background rejection
    +Improved lepton acceptance
    + sifted background discrimination
- 2011 to 2012:
  - Doubled integrated s/√b!
  - Best s/b: ~1:1
- 1-2012/2011 = ~34% stronger expected limits than ZH summer 2011

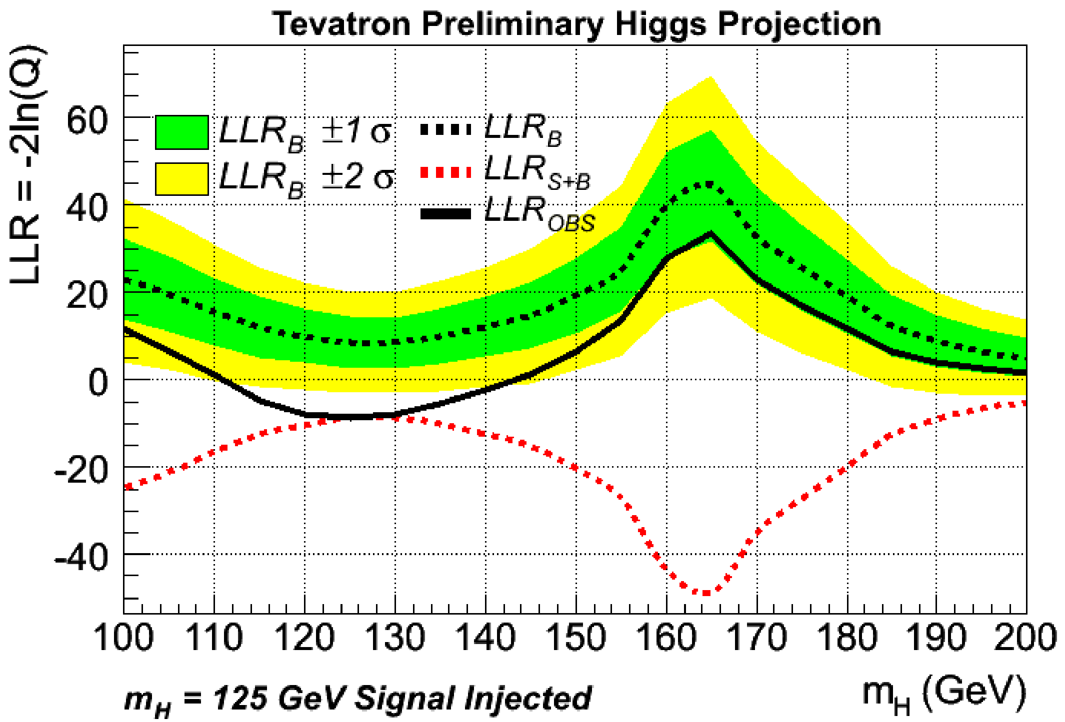




Signal Injection

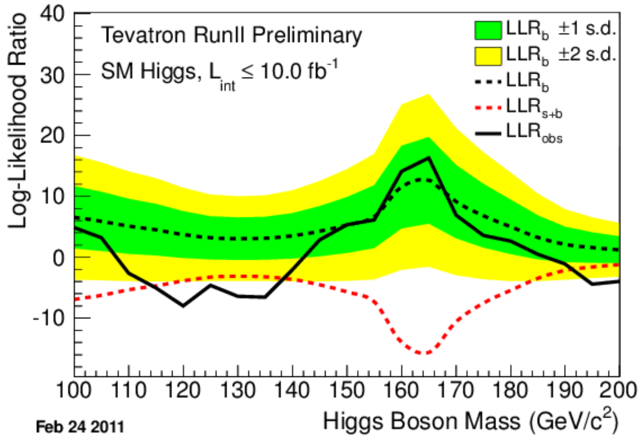


3σ Signal Injection Study

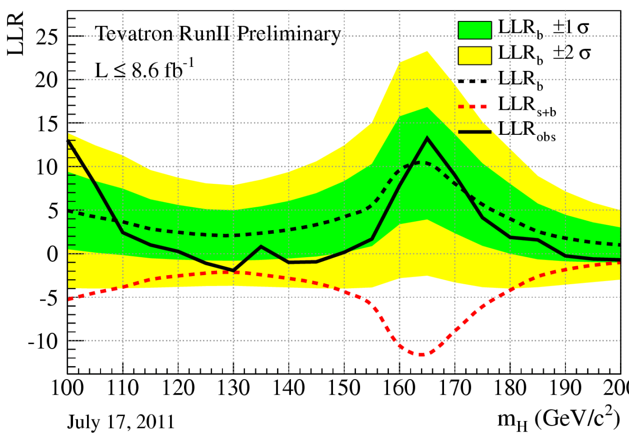


- **Consider a study performed by injecting MH=125 GeV Higgs signal to our search,**
  - **luminosity scaled so the excess is 3 s.d. above the background prediction.**

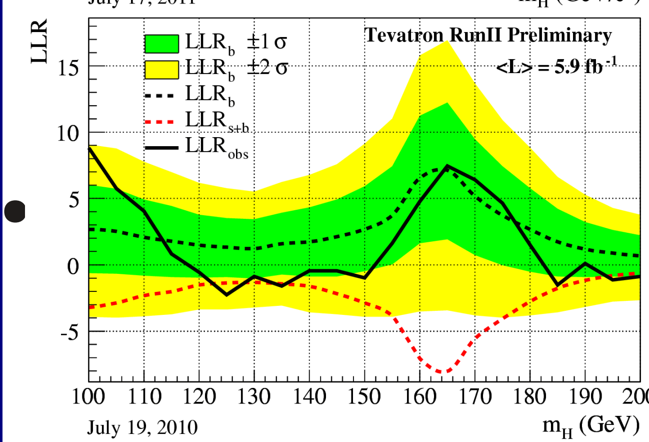
The History of the Search



2012

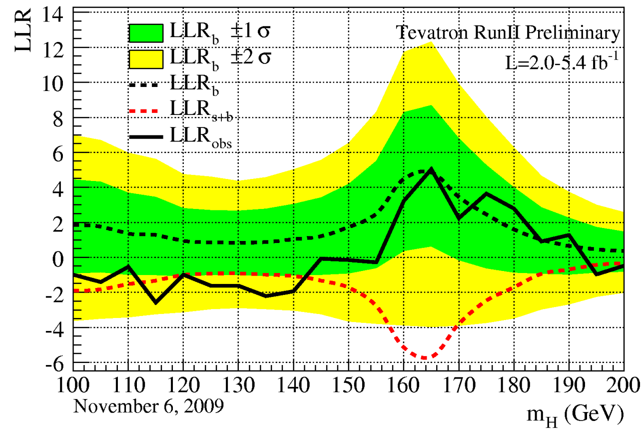


2011

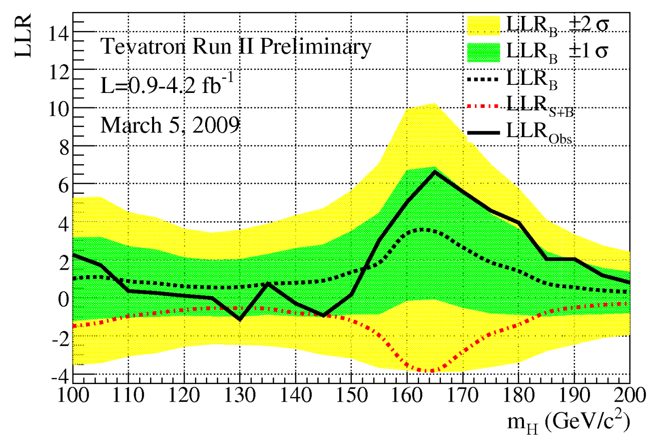


2010

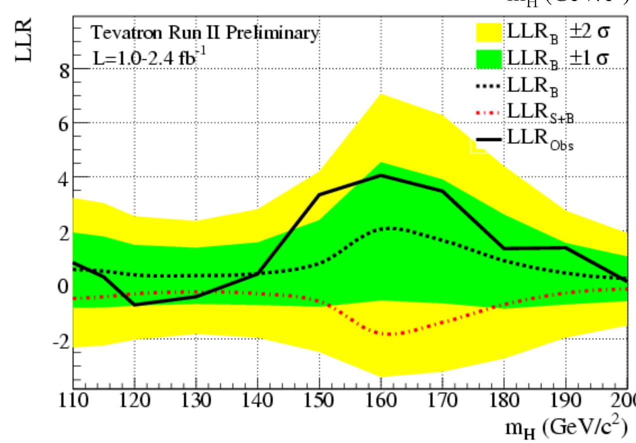
2009



2008

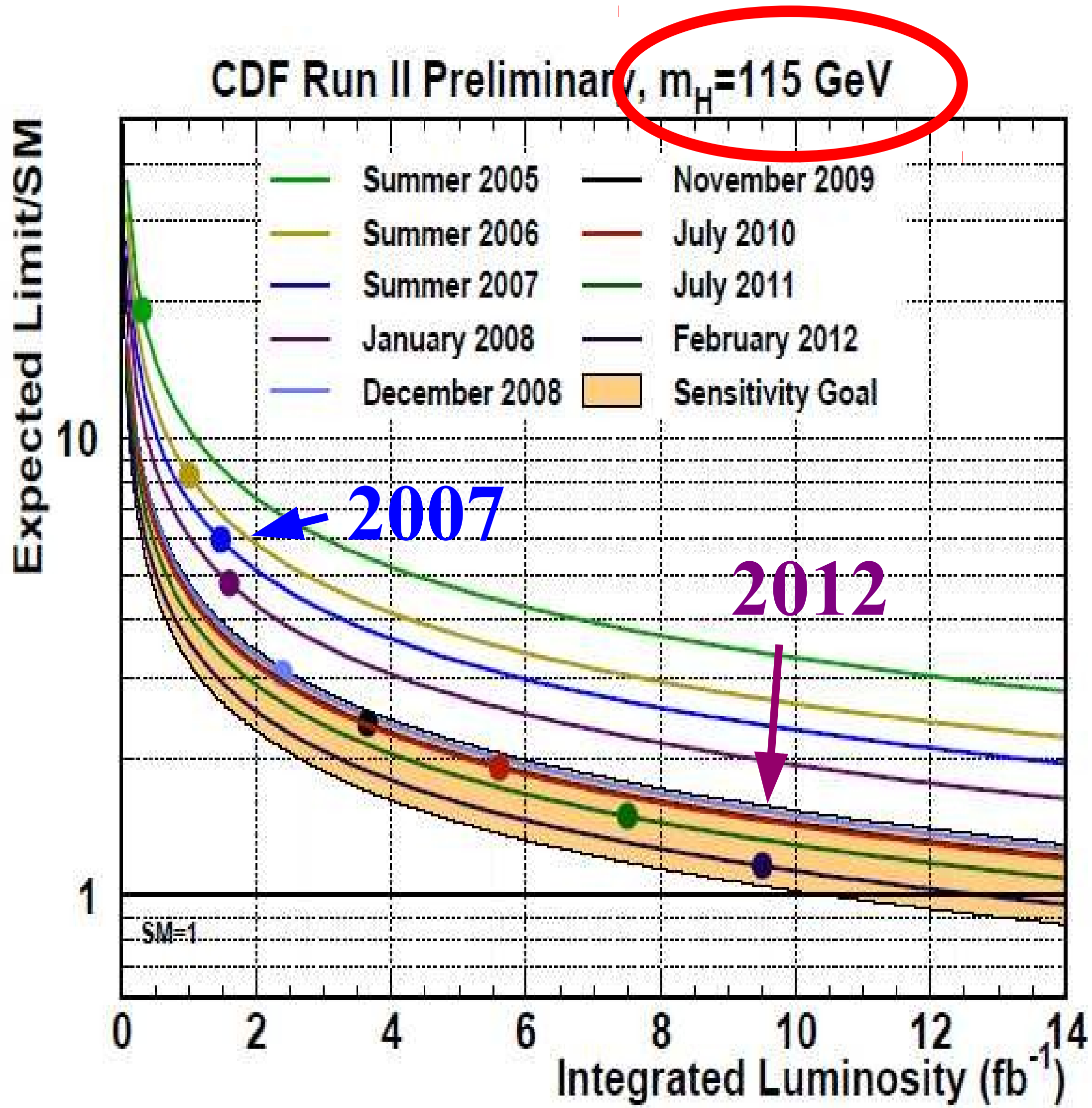


2007



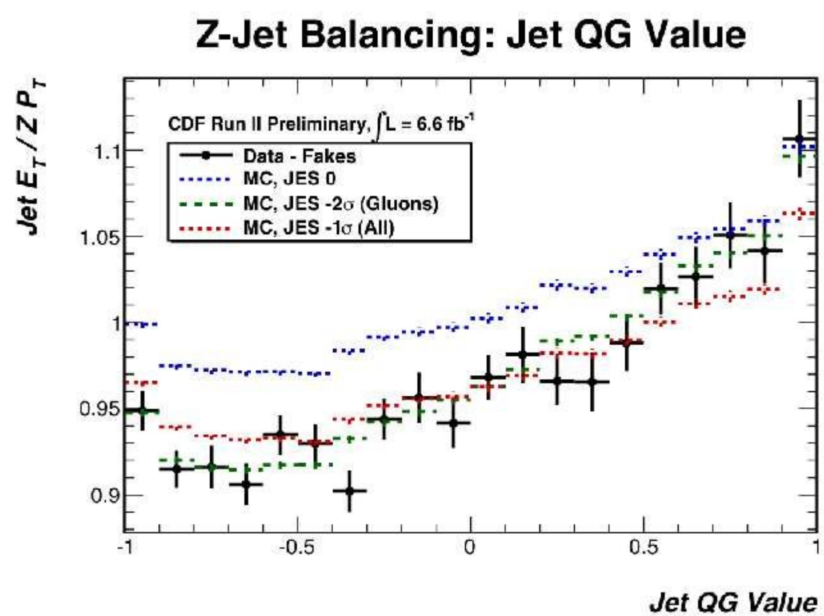
The Path To SM Sensitivity

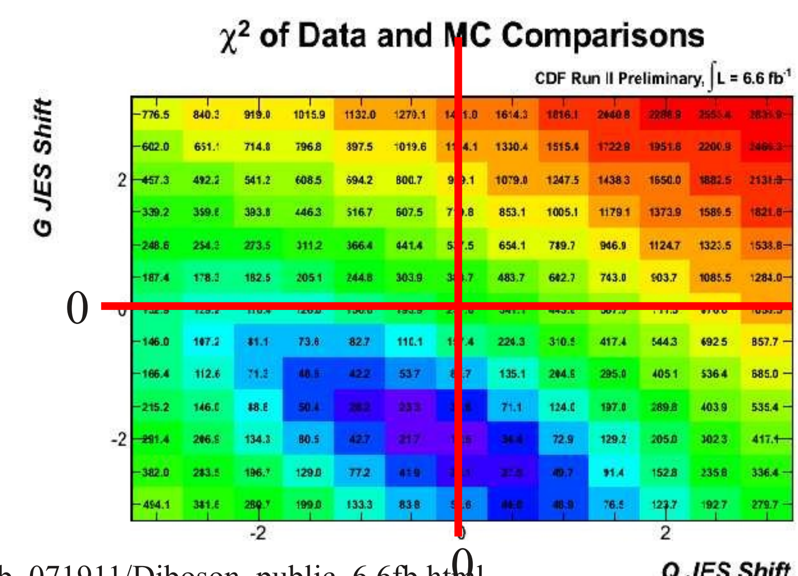
- CDF has reached ~SM Sensitivity
  - Why now?
  - 10/fb and steady progress
    - more decay channels
    - acceptance in old channels
    - Improved reconstruction
    - Improved discrimination
- Since 2007:
  - Factor of ~2 improvements beyond additional data
- Since July 2010:
  - Factor of ~1.5 beyond additional data at low mass



CDF: New Jet Shape Systmatics

- Z+1Jet balancing studies performed
- Poor description of Z-jet balance seen in gluon-like jets.
  - MC gluon jets harder than data in ET by ~2xJES
  - MC quark jets well described
- Origin of mismodeling still under investigation
  - Affects jet energies, dijet mass spectrum of untagged jets
- Negligible effect on tagged samples
- For 2012 results, MC simulation has been corrected for this effect
- Change to expected or observed limits far below other systematics
- For more information:
  - http://www-cdf.fnal.gov/physics/new/hdg/Results_files/results/wzllbb_071911/Diboson_public_6.6fb.html





Effect of Improved Tagging (WH)

- Significant effort to optimize tagging categories and thresholds for loose/tight tagging selections
- 11% gain in S/√B means expected limits lower by ~11%.

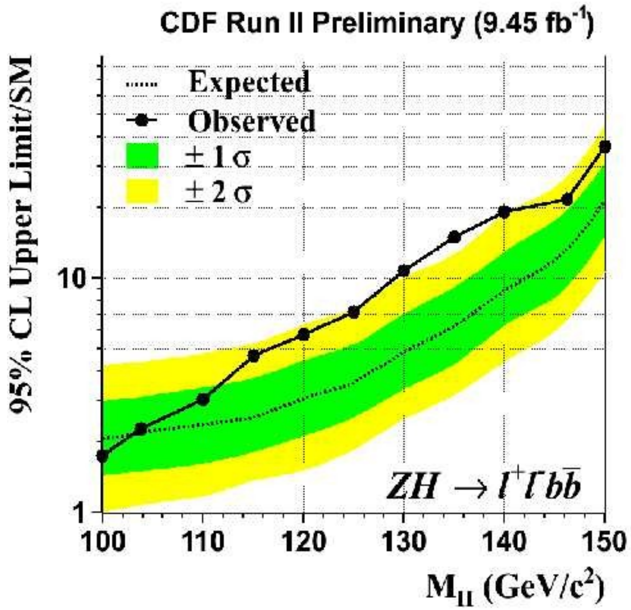
2011

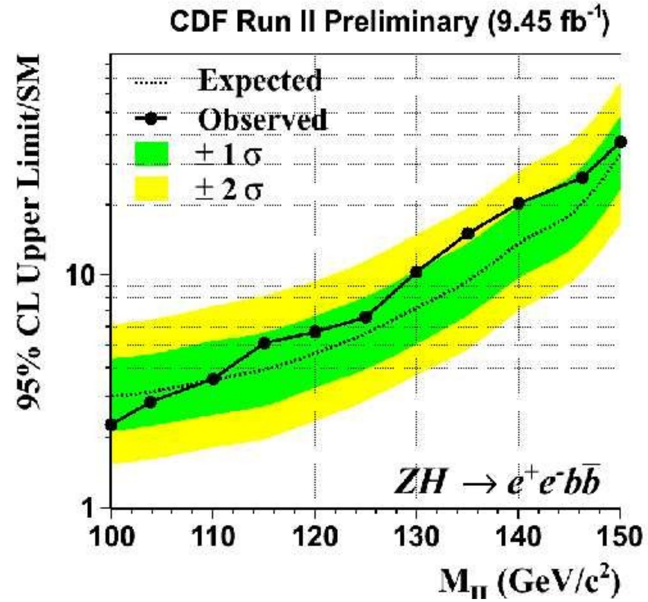
Tagging Category	S/√B
SecVtx+SecVtx	0.228
SecVtx+JetProb	0.160
SecVtx+Roma	0.103
Single SecVtx	0.146
Sum	0.331

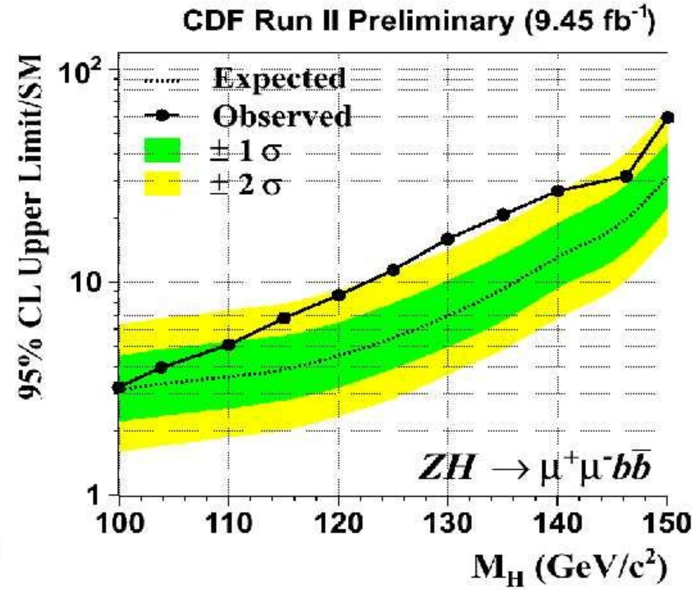
2012

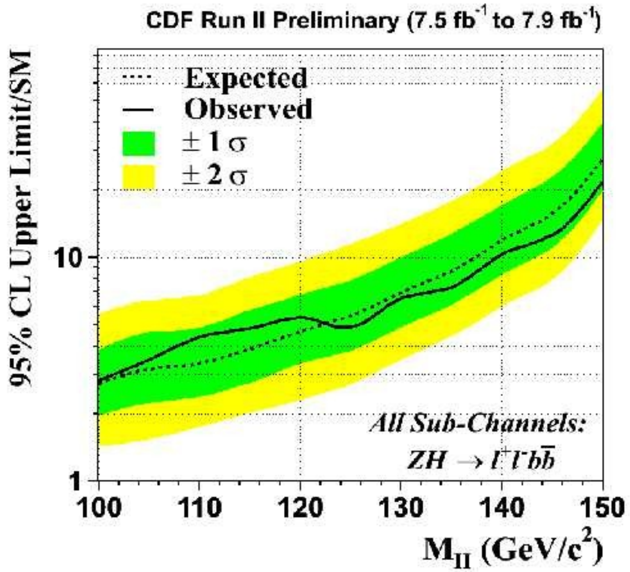
Tagging Category	S/√B
Tight-Tight	0.266
Tight-Loose	0.200
Single Tight	0.143
Loose-Loose	0.053
Single Loose	0.044
Sum	0.369

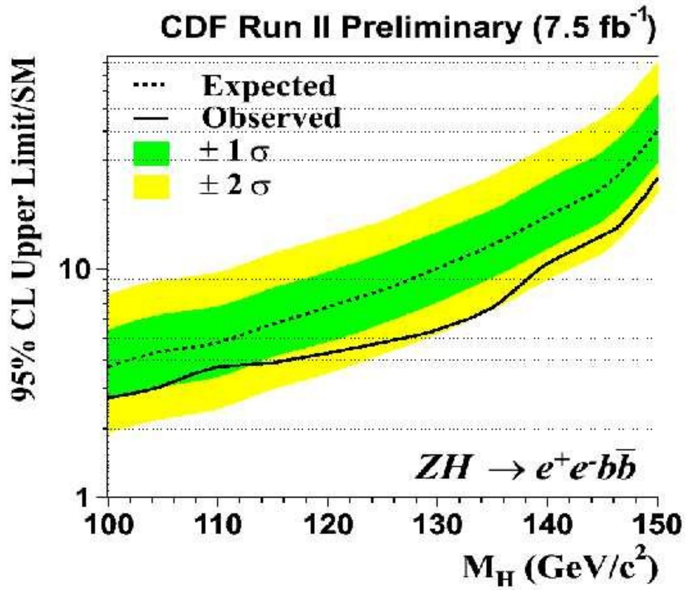
ZH Results: Comparison to 2011

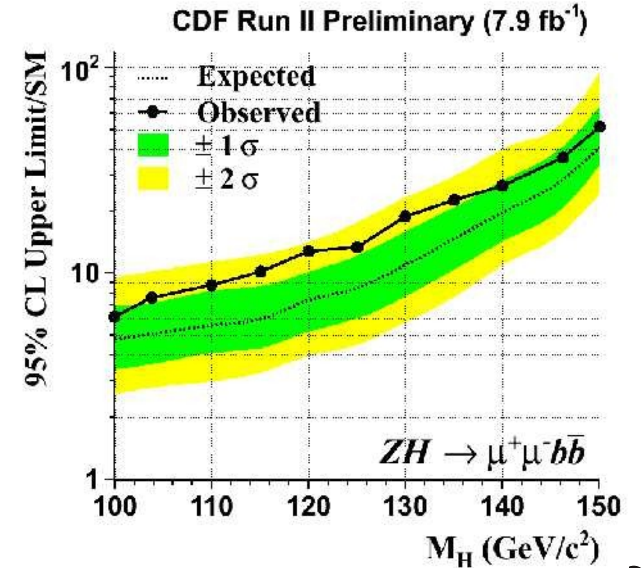




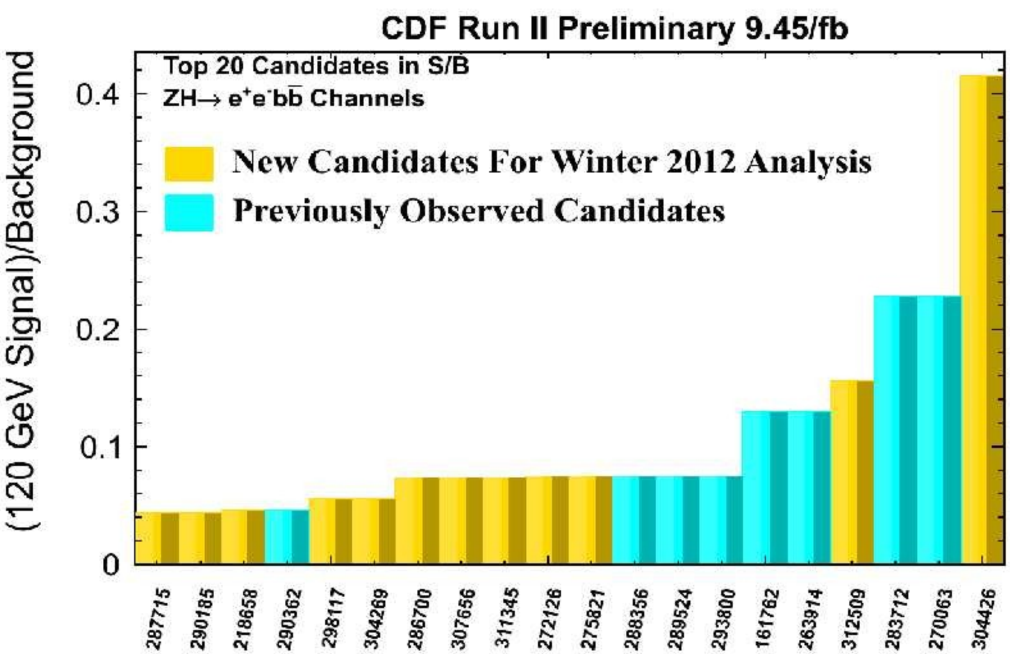


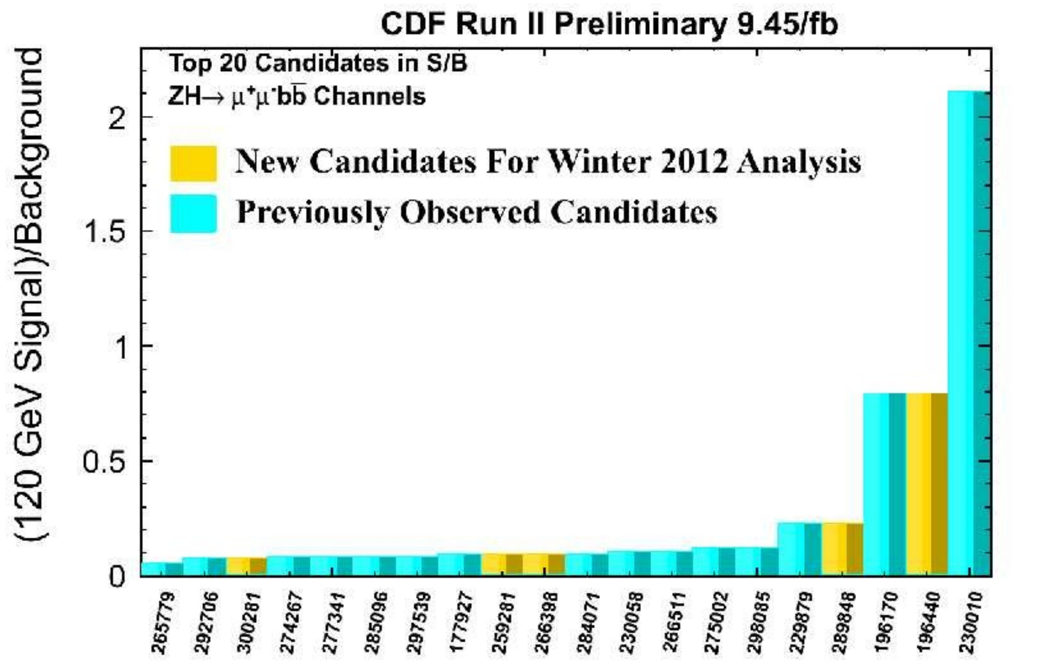


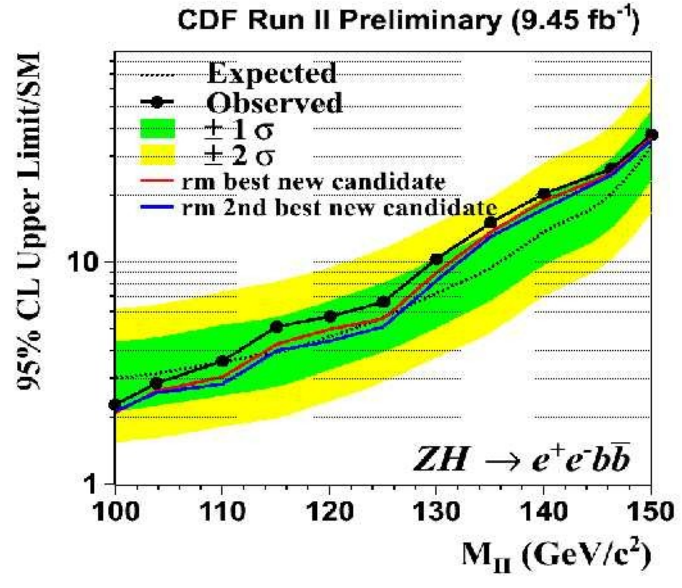




ZH Results: Comparison to 2011

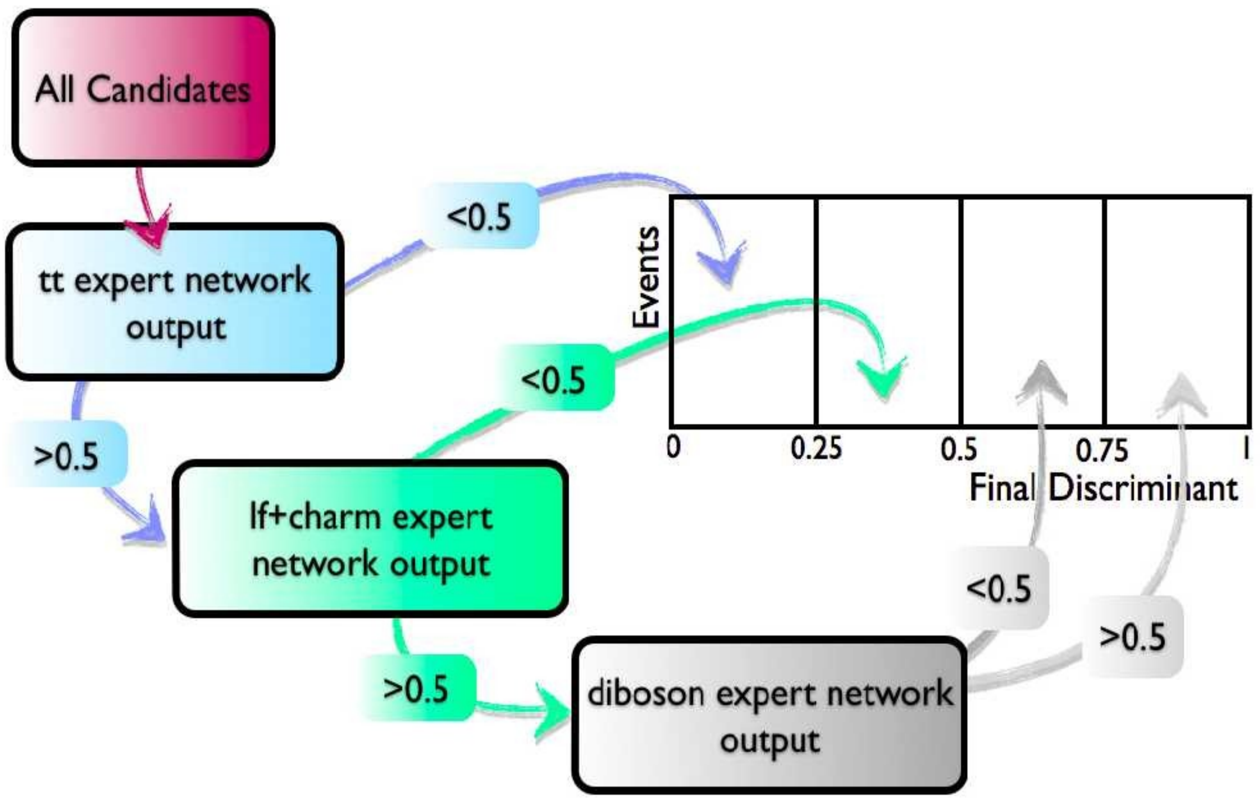






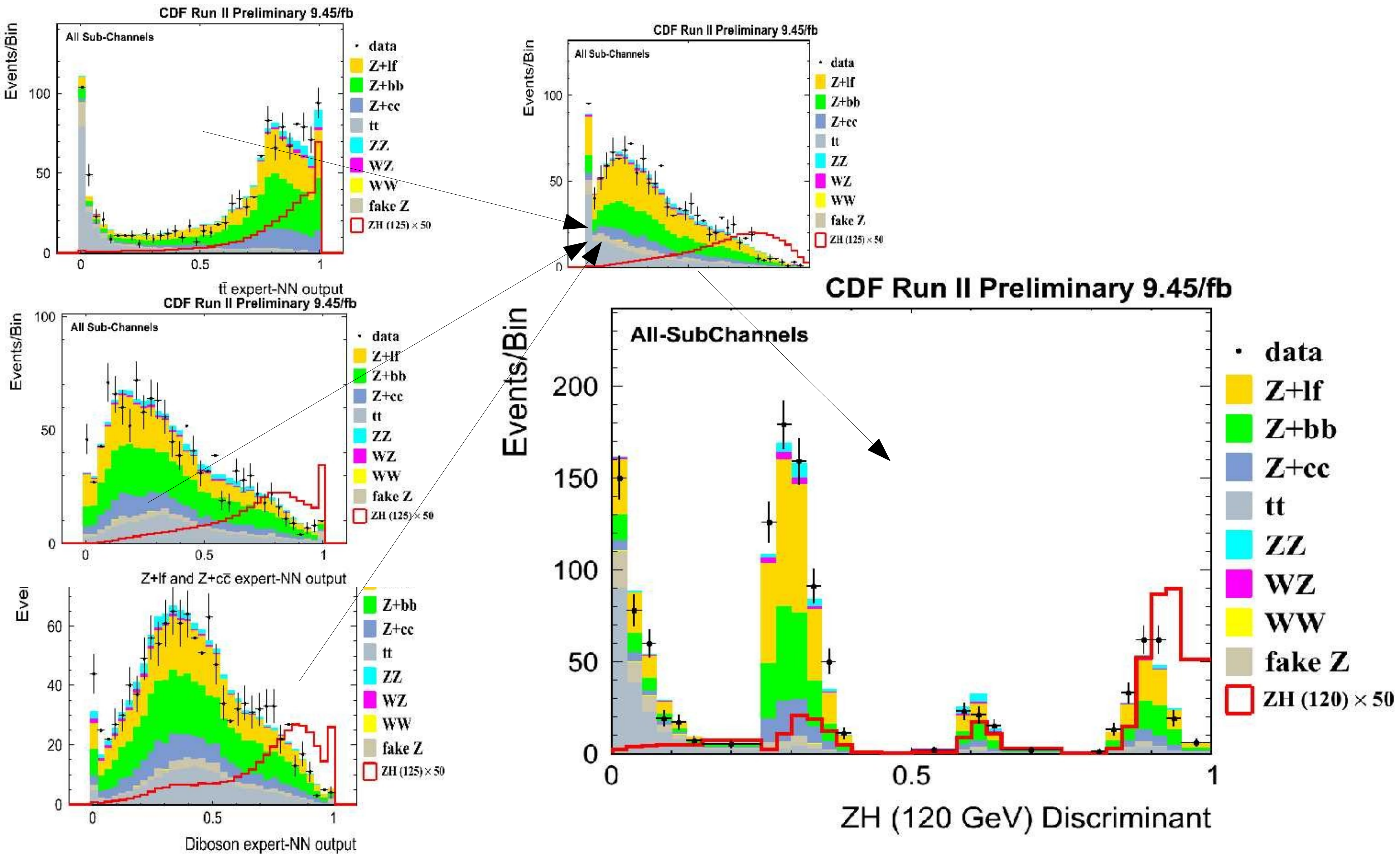
Improved Discrimination

- ZH Analysis now sifts events into 4 categories
  - Non-Z
  - Z+lf
  - VV
  - Z+bb
- Each category then separated for ZH
- Resulted in ~10% improvement over previous discriminant primarily due to removal of VV from ZH region



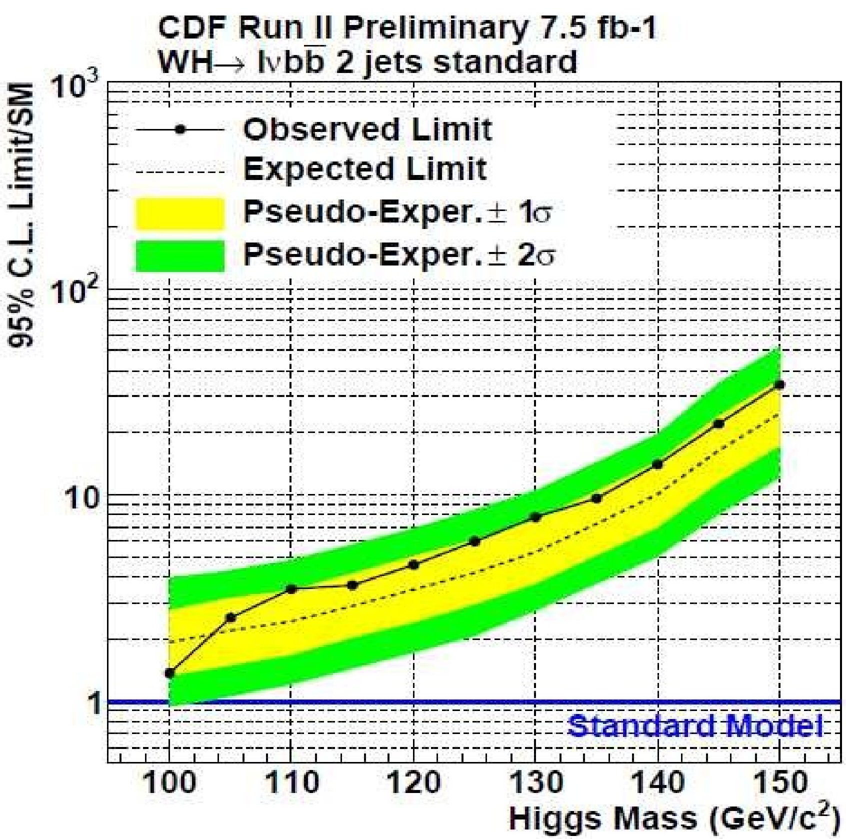
Improved Discrimination

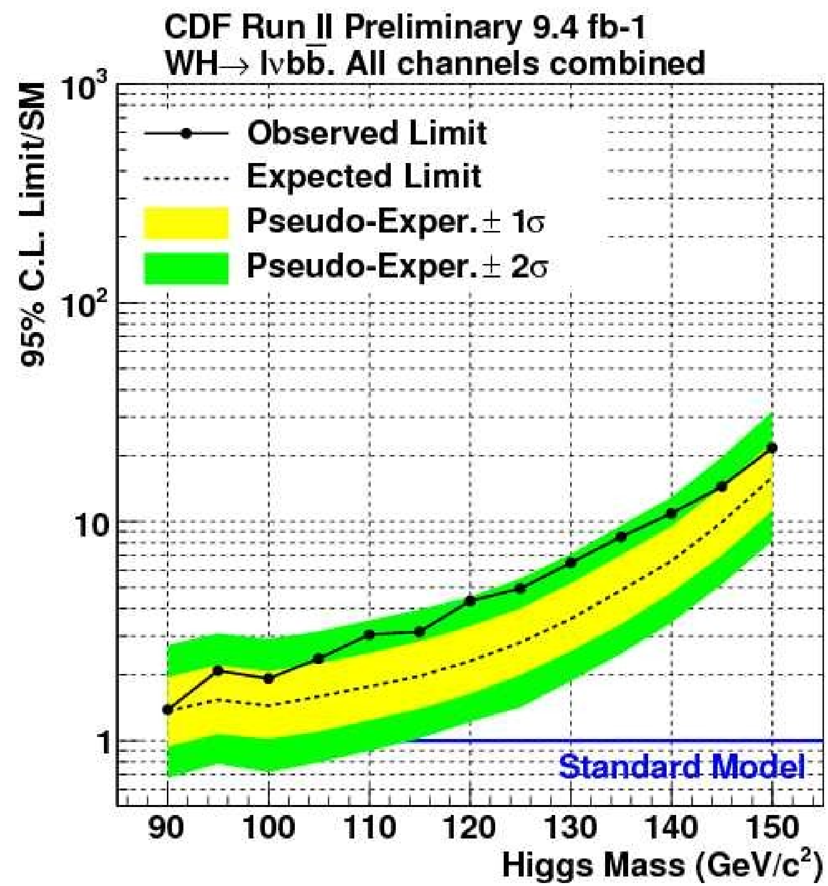
- ZH Analysis now sifts events into 4 categories



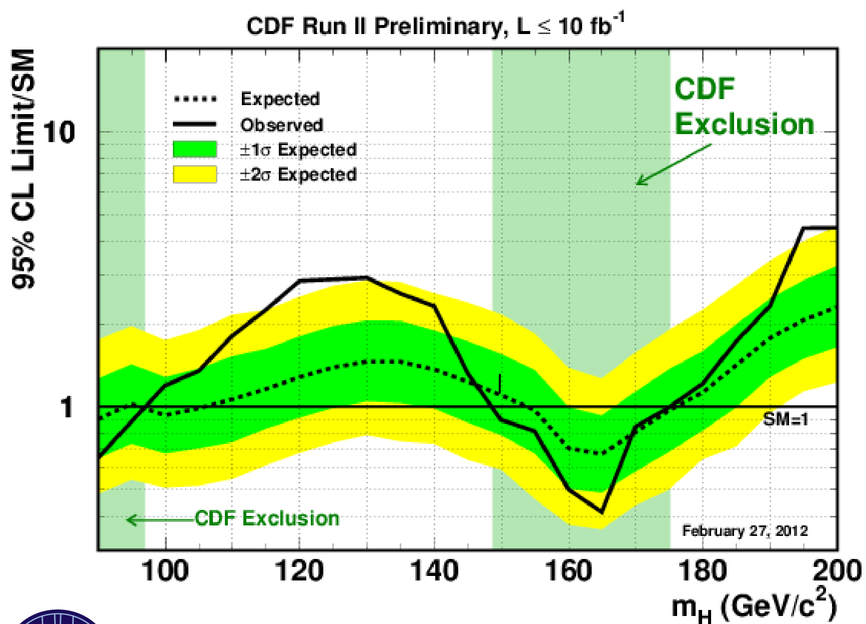
WH: Comparison to 2011 Results

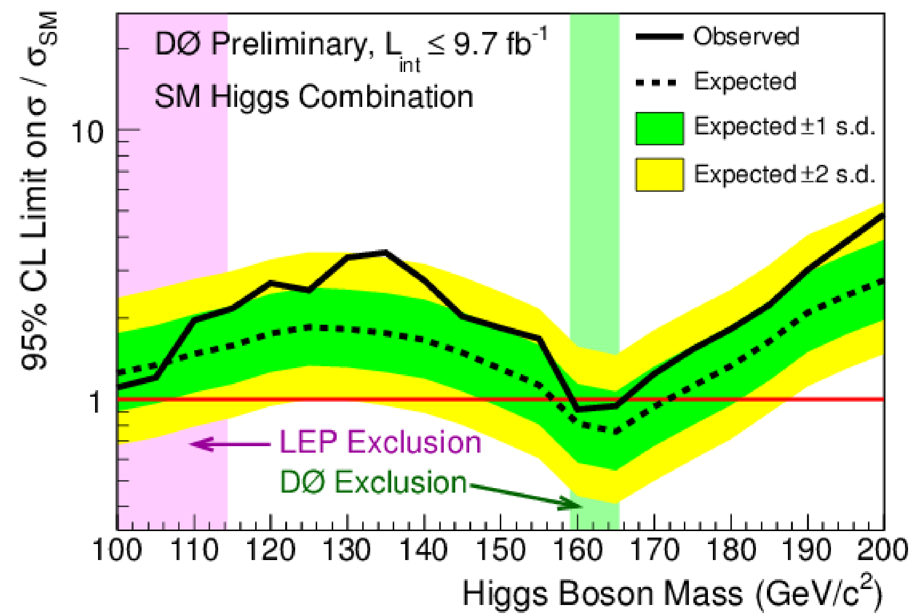
- **Overall shape comparable to 2011 2-jet bin of WH**





Comparing Summer 2011 Limits





Winter 2012

Summer 2011